BOILER DRAUGHT

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BY

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PREFACE

This book was commenced with the object of placing some help in the hands of chief engineers and others, to whom the efficient working of steam plant is of interest and importance. Also to assist them in determining whether the existing arrangements for producing a draught on their boiler fires are as satisfactory as it is possible to make them, or whether a more economical method is available. It was hoped, also, that it might prove a convenience and guide where an entirely new plant is concerned.

The writer does not pretend that there is much that is original in these pages, but his intention is to put the matter which forms the subject of this work in such a way that it will be presented clearly to the reader. Wherever possible, numerical examples are given.

The value of mathematical investigation is well appreciated, but if it is relied on too completely, to the exclusion of practical experience, the results are likely to be greatly misleading. It is for this reason that men of high scientific attainments are sometimes at fault when they have to tackle a problem in practical work.

Thanks are due to the different firms who have kindly placed at the writer's disposal drawings, etc., of the

various apparatus and machinery that they manufacture, and especially to Messrs. Bumsted & Chandler, Ltd., whose assistance on the subject of induced draught, drawn from their great experience of this system, has been invaluable.

To Mr. J. M. Kennedy thanks are also due for his trouble in supplying me with various items of information.

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CHAPTER I

DRAUGHT

As is well known, oxygen is necessary for the combustion of fuel. This oxygen is supplied by the atmosphere, which is composed of twenty-one parts of oxygen to seventy-nine parts of nitrogen. To burn fuel efficiently, so as to get the greatest possible heat therefrom, some means must be employed to draw the air through it, at a high enough velocity to supply all the oxygen that is required, that is, to cause a draught, otherwise the fire would burn but slowly, and very little heat would be given off.

There are several ways of producing this draught. These may be divided into two sections, which are: those that draw the air through the fire by suction, and those that force it through under pressure.

In the first division the apparatus most usually met with is the ordinary chimney, generally built of brick, but sometimes of steel. As everyone is aware, this is simply a tall hollow column, up the centre of which the hot gases produced by the combustion of the fuel ascend. Its height is determined by the duty that it will have to perform. Sometimes only a small chimney is built, and a draught is induced by placing a steam jet inside. The

steam used to supply the jet is often the exhaust steam from an engine.

A third method is to place a mechanically driven fan at the end of the boilers, to act upon the fires in the same manner as a chimney, and this is known as induced draught. When this system is employed it is possible in some localities to dispense with a chimney altogether.

All these arrangements have the same effect upon the fires, that is, they draw the air through the fuel by causing a partial vacuum in the flues.

In the second division are those systems which work by forcing the air through the fuel, and are those arrangements in which the space below the firebars is closed, and air is forced in under pressure by the action of steam jets. The Meldrum furnace is a typical example of this. Another system is that in which air is forced under pressure, by means of a mechanically driven fan, into closed ashpits, and thence through the fires. All these systems have their merits and demerits, which will be carefully described in the following chapters. They all are designed with the same object in view, namely, to supply the fuel on the firebars with sufficient oxygen, and thereby to maintain as high an efficiency of combustion as possible.

In the following chapters the various systems are described, together with other information that bears upon the subject-matter of the volume.

CHAPTER II

CALCULATIONS RELATING TO AIR

This chapter is devoted to explanations of the rules and formulæ concerning air, especially such as are required when dealing with large volumes at low pressures.

When calculating the weight of a specified volume of air at different temperatures the absolute temperature must be used, not that registered by the thermometer. This temperature is that shown on the thermometer, plus 461° if the thermometer in use is calibrated in Fahrenheit degrees, but if in centigrade degrees then 273° must be added.

The manner in which the above figures are arrived at is fully explained in many of the engineering text books, amongst others in Professor W. J. M. Rankine's book on the steam engine, and other manuals dealing with similar subjects. From any of these publications the necessary information will be gained by readers who do not already know how these figures are arrived at.

The volume of a certain weight of air, or the weight of a known volume of air, can easily be calculated for different temperatures, when these have been obtained. The volume of a fixed weight of air is directly proportional to its absolute temperature, while the weight of a known volume is inversely proportional to the absolute temperature when the pressure remains constant.

As an instance, the volume of 1 lb. of air at 32° F. is 12·36 cubic feet, but if it is raised to 500° F. in temperature, the volume it will then occupy is—

$$\text{Volume} = 12{\cdot}36 \times \frac{500 + 461}{32 + 461}$$
$$= 12{\cdot}36 \times \frac{961}{493}$$
$$= 24{\cdot}1 \text{ cubic feet.}$$

Therefore its volume will be almost doubled.

Again a cubic foot of air at 32° F. weighs 0·0807 lb., while its weight at 500° F. will be—

$$\text{Weight} = 0{\cdot}0807 \times \frac{32 + 461}{500 + 461}$$
$$= 0{\cdot}0807 \times \frac{493}{961}$$
$$= 0{\cdot}0414 \text{ lb.}$$

For the use of readers, the weight of a cubic foot of air, and also the relative volumes, have been calculated between 32° and 700° F. at atmospheric pressure.

These values will be found in Table I.

The air pressure used in conjunction with boiler draught, whether it is obtained by natural or mechanical means, is, comparatively speaking, very slight. On this account it is customary to measure it in inches of water, the instrument used being known as a water-gauge. Although many readers who take up this book are probably well acquainted with it, a detailed description may not be out of place. A water-gauge can very easily be made by anyone who is a handy man.

A mahogany board, as seen at *A* in Fig. 1, should be procured, with a glass U tube B B_1 mounted upon it, and attached by small brass clips as seen at *E*. It will

be noticed that the tube is bent at D to form a right-angle with the leg B_1. This is done to allow an india-rubber pipe to be fixed, so that the water-gauge can be connected up to the interior of the chimney. A movable scale, marked in inches, should be fixed between the two

Table I.

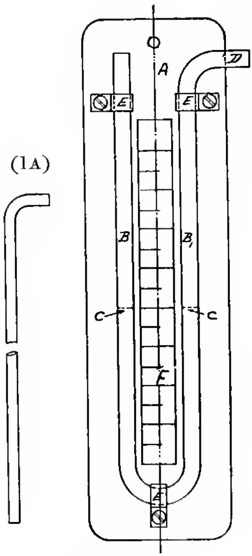
Tempr. deg. F.	Relative Volume.	Weight of a cubic foot in lbs.	Tempr. deg. F.	Relative Volume.	Weight of a cubic foot in lbs.
0	0·935	·0864	170	1·279	·0630
10	0·955	·0844	180	1·299	·0620
20	0·975	·0827	190	1·320	·0611
30	0·995	·0810	200	1·330	·0601
32	1·000	·0807	225	1·374	·0579
40	1·016	·0794	250	1·444	·0559
50	1·036	·0778	275	1·495	·0540
60	1·056	·0763	300	1·546	·0522
70	1·076	·0749	325	1·597	·0506
80	1·097	·0735	350	1·648	·0490
90	1·117	·0722	375	1·689	·0477
100	1·137	·0710	400	1·750	·0461
110	1·157	·0696	450	1·852	·0436
120	1·178	·0684	500	1·954	·0413
130	1·198	·0673	550	2·056	·0384
140	1·218	·0661	600	2·158	·0376
150	1·239	·0651	650	2·260	·0357
160	1·259	·0640	700	2·362	·0338

vertical portions of the glass tube, as seen at F in the figure. When required for use, the tube must be filled with water, until it stands at a height as indicated by the dotted lines at C C. The water should preferably have been stained, so as to make it easier to read. The writer has found an infusion of coffee very useful for

this purpose. After the liquid has been put in it will naturally stand at the same height in each of the vertical portions of the tube. The scale F must now be moved until the zero line, which is in the centre of it, is at exactly the same height as the level of the water. A convenient length of rubber piping must be obtained, one end of which is attached to D, and the other end to a small iron tube, which must be introduced such a distance into the chimney or fan inlet that the end of it is about in the middle of the stream of gases, of which particulars are required. The iron tube should have the end bent, as seen in Fig. 1A, and, when a reading is being taken, care must be exercised to see that the inlet of the pipe faces the stream of gases. It is a good thing to pack the end of the pipe very lightly with cotton wool, so as to damp down the oscillations of the column of water, which will enable a more accurate reading to be taken. On inspecting the instrument, when it is connected up to a chimney or the inlet of an induced draught fan, it will be noticed that the water in B_1 has risen, while that in B has fallen. If the water-gauge had been connected to the discharge of a forced draught fan, the water in B_1 would have been depressed, while that in the other leg would have risen. Whether forced or

(1)

(1A)



FIGS. 1, 1A.

induced, for a similar intensity of draught, the difference in the levels would have been the same. Now the vertical distance between the surfaces of the two columns of water, as read off on the scale F, is a measurement of the intensity of the draught in inches of water, and is usually spoken of as so many inches water-gauge pressure. Thus, if there is a difference of 1 inch between the two levels, it means that the air pressure which is being investigated is just equivalent to the pressure exerted by a column of water one inch high.

It is known that a cubic foot of water, at ordinary temperatures, weighs about 62·4 lbs., and from this it is easily calculated that each inch in height of this cube of water is equivalent to

$$\frac{62{\cdot}4}{12} = 5{\cdot}2 \text{ lbs.}$$

Therefore, on the base of this cubic foot, that is, on 1 square foot, each inch of water exerts a pressure of 5·2 lbs.

If great exactness is required, one must take the actual weight of a cubic foot of water at the corresponding temperature. Thus, if the water is at 50° F., then the pressure per square foot for each inch is

$$P = \frac{62{\cdot}409}{12} = 5{\cdot}2,$$

while, if the temperature is 70° F., the weight per cubic foot is 62·313 lbs., and the pressure per square foot per inch water-gauge is 5·192. This is a refinement which, in general practice, is not necessary, as it is impossible to read an ordinary water-gauge to such a degree of accuracy, that the actual weight of a cubic foot of water signifies, at ordinary temperatures.

Table II. gives the weight of a cubic foot of water at various temperatures.

TABLE II.

WEIGHT OF A CUBIC FOOT OF WATER AT VARIOUS TEMPERATURES.

Deg. F.	Weight.	Deg. F.	Weight.
32	62·418	95	62·074
35	62·422	100	62·022
40	62·425	110	61·868
45	62·422	120	61·715
50	62·409	130	61·563
55	62·394	140	61·381
60	62·372	150	61·201
65	62·344	160	60·991
70	62·313	170	60·783
75	62·275	180	60·548
80	62·232	190	60·314
85	62·182	200	60·081
90	62·133	212	59·64

It is often useful to express the water-gauge reading in ounces per square inch, and it can easily be shown, that 1 inch water-gauge pressure equals 0·578 oz. per square inch, and is also equivalent to 0·0361 lb. per square inch.

For a further appreciation of this subject, it is necessary to consider the laws governing the movement of air. The method of ascertaining the pressure has already been explained, and the next thing to do is to find out the velocity of the current of air undergoing investigation. This is obtained by means of an instrument called an anemometer, which consists of a small

and very light revolving element somewhat like a miniature windmill. This is fitted with a spindle, geared to a train of wheels, which operate a number of hands that move over dials, much after the fashion of the dials and hands on a gas meter which indicate the amount of gas passing through it.

In Fig. 2 will be seen an outline of an anemometer in which *A* is the small impellor.

B is the case containing the dials and necessary gearing.

C is a small stop for putting the dials in and out of action.

D is a small swivelling socket by which the instrument can be attached to a staff, which enables readings to be taken without the necessity of the operator standing in the current of air. When this instrument is placed in the stream of air, delivered by a fan or other apparatus, the small impellor revolves. This actuates the hands of the

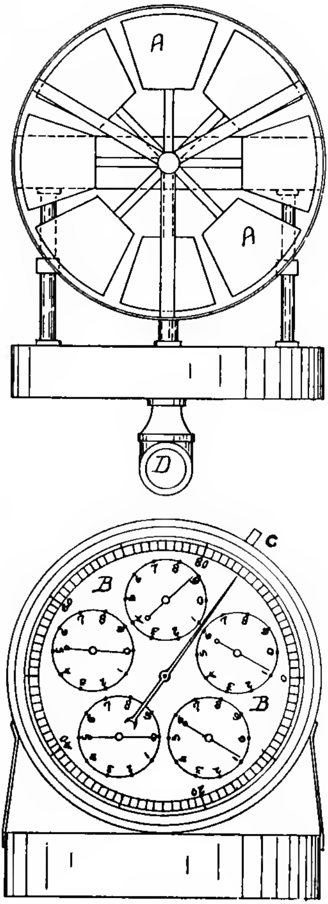


Fig. 2.

measuring dials, and so the velocity of the air in a given time can be ascertained. These instruments are calibrated for air at ordinary temperatures, and should only be used in such, as they are much too delicate to be placed in the hot gases in boiler flues. Where an induced draught plant or chimney is installed, an idea of the amount of air being dealt with can be obtained by using one of these intruments at the entrance of the boiler

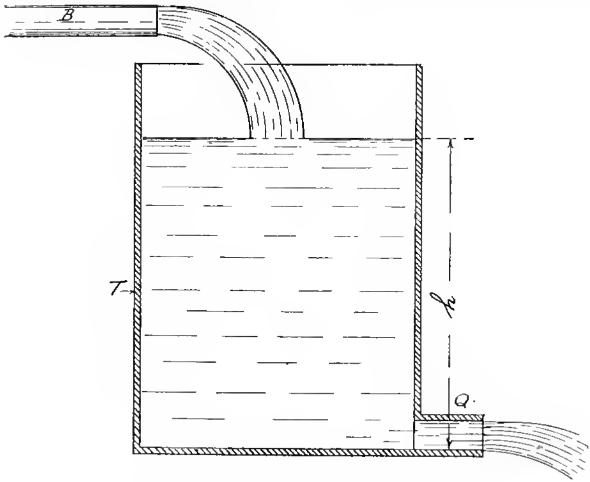


FIG. 3.

furnaces, that is, the ash-pit below the fire-bars. For a forced draught plant the instrument can be used in the fan inlet, and in this way the exact amount of air that the fan is passing can be ascertained.

Some people prefer to work out the velocity from the known head, as obtained by calculation from the water-gauge reading, believing this to be the more accurate method, because an anemometer is easily put out of order, especially when used in currents of air at high velocities.

It is a simple matter to calculate the actual velocity due to the air pressure, the law governing this being exactly similar to that by which the velocity of discharge of water from a tank due to a given head is obtained. Looking at Fig. 3, T is a tank containing water, which is kept at a constant head by the supply pipe B. The discharge orifice is seen at O. A certain pressure is maintained at O which is equal to the head h multiplied by the density of the liquid.

Let h = head.

d = density.

p = pressure.

Then $p = hd$.

As it is arranged that the supply B shall keep the head constant, the pressure at the orifice, due to the head, will obviously be unchanged, and the water will flow by gravity, the rate of discharge being entirely governed by the head, if the effect of friction is neglected. In actual practice the velocity of flow is modified by frictional and other resistances. If this were not so, the velocity of flow would be exactly that due to the head, or, in other words, it would be exactly equivalent to the velocity of a body acted on by gravity, which had been made to fall from a height equivalent to the head h, so that it is an easy matter to determine the velocity from the well-known formula for falling bodies which is

$$V = \sqrt{2\,gh},$$

where V = velocity in feet per second

g = acceleration due to gravity = 32 feet per second per second in round numbers.

The above formula may be written thus

$$V = 8\sqrt{h}.$$

The total head h is the only means for procuring the

movement of the water or air, as the case may be, but this head has not only to produce the velocity; it has also to overcome any resistance to its flow. In practical work this resistance is represented by pipe or flue friction, or changes in direction of flow, etc. That portion of the total head which is required to produce the necessary velocity is termed the *velocity head*, while that required to overcome friction is termed the *pressure head*, so that

Total head = Velocity head and pressure head.

From the above it is obvious that in a system of pipes or flues, through which water or air is passing, the velocity will decrease as the resistance is increased, unless the total head is sufficiently augmented to overcome the additional resistance. It has already been shown that the pressure is equal to the density multiplied by the head, and using the same symbols it is evident that

$$h = \frac{p}{d}$$

Referring to the formula for velocity, it will be noticed that the velocity is not in any way connected with the weight of the material in question, but simply with the head or height h from which it falls. This only determines the velocity. It therefore follows from the formula

$$h = \frac{p}{d}$$

that the less the density the greater the head, and consequently the higher the velocity of efflux. It will be evident, when dealing with gases, whose density is very much less than liquids, that the velocity for a given pressure will be many times greater.

Before the velocity can be calculated, it is first necessary

to determine the head. Now the standard atmospheric pressure, from which all these calculations are made, is that of 14·7 lbs. per square inch, which is equal to 29·9 inches as shown on the barometer. The weight of a cubic foot of air at this pressure, and at a temperature of 32° F., has already been given, and is 0·0807 lb., therefore to find this head proceed in the following manner :—

Let h = the required head as before,
P = water-gauge reading in inches,
D = density of water.
d = density of air.

then
$$h\,d = \frac{P}{12} \times D$$

therefore
$$h = \frac{D \times P}{12 \times d},$$

from which the velocity of the air due to the head can be found as already explained. Example :—Suppose that it is necessary to find the velocity due to an air pressure equivalent to 4 inches water-gauge, when the temperature of the atmosphere is 32° F. At this temperature the density of water is such that a cubic foot weighs 62·418 lbs., therefore

$$h = \frac{62{\cdot}418 \times 4}{12 \times 0{\cdot}0807} = 257{\cdot}8 \text{ feet},$$

and the velocity due to this head will be

$$\begin{aligned} V &= 8\sqrt{257{\cdot}8} \\ &= 128{\cdot}4 \text{ feet per second.} \end{aligned}$$

To obtain the greatest accuracy it will be seen from the above that it is necessary to have the temperature of both air and water, because the head will change with any variation of these temperatures, on account of the alteration which takes place in the density of the two

substances. Of course, when very great accuracy is required it is also necessary to take into account three

TABLE III.

Pressure in Inches of Water at 32° F.	Head in Feet.	Velocity: Feet per Sec.	Velocity: Feet per Min.
0·1	6·44	20·3	1221·6
0·2	12·89	28·8	1731·0
0·3	19·33	35·2	2115·6
0·4	25·78	40·7	2443·2
0·5	32·22	45·5	2731·2
0·6	38·67	49·8	2992·2
0·7	45·11	53·8	3232·2
0·8	51·56	57·5	3455·4
0·9	58·00	61·0	3664·8
1·0	64·45	64·3	3862·8
1·2	77·34	70·5	4231·8
1·4	90·23	76·2	4570·8
1·6	103·12	81·4	4885·8
1·8	116·01	86·4	5182·8
2·0	128·90	91·0	5463·0
2·5	161·12	101·7	6102·6
3·0	193·35	111·5	6691·2
3·5	225·57	120·4	7227·0
4·0	257·80	128·4	7726·2
4·5	290·02	136·6	8194·8
5·0	322·25	143·9	8638·2
5·5	354·47	151·0	9060·0
6·0	386·70	157·7	9462·6
7·0	451·15	170·3	10219·2
8·0	515·60	182·1	10926·6
9·0	580·05	193·1	11589·0
10·0	644·5	203·6	12216·0

things: the increased density of the air due to the pressure, the exact height of the barometer, and the amount

of moisture in the air. This accuracy is only necessary in the case of delicate laboratory investigation, but for ordinary commercial purposes these further refinements are quite useless, and only complicate and tend to obscure the results of any tests that are taken.

In Table III. are given the velocities per second and per minute, due to different heads, for air at a temperature of 32° F. and at standard atmospheric pressure.

The next point of interest is the horse-power that is represented by the movement of air. It has already been explained that 1 inch air pressure is equal to 5·2 lbs. pressure per square foot. Now if the water-gauge reading is multiplied by this figure, and by the velocity of air passing per minute, and the area of discharge, it will be seen that the result is in foot lbs., because it represents the distance moved through in feet, against a certain resistance in pounds. If the result so obtained is divided by 33,000, that is, the number of foot pounds in one horse-power, the result is the actual horse-power which is necessary to move the air.

That is, if $A\,H\,P =$ air horse-power,

$O =$ area of orifice,

$V =$ mean velocity of air in feet per minute,

$P =$ water-gauge reading in inches.

then $$A\,H\,P = \frac{5{\cdot}2 \times P \times V \times O}{33{,}000}.$$

This, of course, assumes an ordinary temperature of air.

It often happens that the air has to be conveyed through ducts of a considerable length, and, where this is necessary, due allowance must be made for loss of pressure occasioned by the friction of the air passing

along them. The resistance caused by this friction gives rise to a loss of head, which may be calculated very closely from this formula given by Mr. Thomas Box in his work on "Heat":

$$h = \frac{C^2 \times L}{(3{\cdot}7d)^5}.$$

where L = length of pipe in yards.
d = diameter in inches.
c = cubic feet of air per minute.

The head, as calculated above, must be added to that actually required for the efficient working of the boilers, so as to obtain the total head which the fan will have to maintain. By examining the above formula it will be seen that the head varies in proportion to the length of the duct, and inversely as the fifth power of the diameter. From this it will be evident that the diameter of the ducts should be kept reasonably large so as to reduce the loss of head as much as possible. Of course, after a certain point is reached, a further attempt to reduce this loss will result in so great an increase in the initial expenditure, and the corresponding high charges for depreciation and interest, that the ultimate cost will more than balance the saving due to the low velocity of the gases. To avoid loss by friction as much as possible bends should only be allowed where absolutely necessary, and should be made of a large radius, in order to place as little resistance as may be in the path of the gases.

Up to the present, no mention has been made of the effect of an alteration of temperature upon the movement of air by mechanical means. It has been shown that the volume of a fixed weight of air is directly proportional to its absolute temperature.

Let t = lower temperature,
t_1 = higher ,,
x = volume corresponding to t,
x_1 = ,, ,, ,, t_1,
w = weight corresponding to t,
w_1 = ,, ,, ,, t_1,
V = velocity corresponding to t,
V_1 = ,, ,, ,, t_1,

then
$$x_1 = x \times \frac{t_1 + 461}{t + 461},$$

and it has also been seen that the weight of similar volumes of air at different temperatures is inversely proportional to the absolute temperatures, which, put into a formula, is

$$w_1 = w \times \frac{t + 461}{t_1 + 461}.$$

It is obvious that when a fan is required to give a certain water-gauge, it will have to run at a higher speed if the temperature is raised, for it will be remembered that

$$V = 8\sqrt{h}$$

and also that

$$h = \frac{p}{d}.$$

It therefore follows that the velocity necessary varies as the square root of the head, that is

$$V \propto \sqrt{h}.$$

Seeing that the density varies inversely as the temperature, the former will be lowered if the latter is raised, which will increase the head, so that it is evident that the speed which it is necessary to maintain, to keep the water-gauge the same with different temperatures, varies

in direct proportion as the square root of the absolute temperature.

So that, if V represents the velocity at the higher temperatures,

$$V_1 = V\sqrt{\frac{t_1 + 461}{t + 461}}.$$

It will now be useful to see in what way the temperature affects the speed of the fan which it is necessary to maintain in order to pass the same weight of air in a given time. In the first place, it is assumed that the fan will deal with an equal volume of air per revolution whether it is hot or cold, which, in practice, actually happens. It will therefore easily be seen that the revolutions will necessarily increase in exact proportion to the absolute temperature.

Let S = revolutions per minute corresponding to t,

S_1 = ,, ,, ,, ,, ,, t_1,

then $S_1 = S \times \dfrac{t_1 + 461}{t + 461}$.

The power that is necessary to move air at higher temperatures next claims attention. As already seen, the power is found by multiplying a velocity by a resistance. A reference to the formula for finding the air horse-power will now be useful. It is known that the velocity varies as the square root of the absolute temperature, also that the area must necessarily vary as the velocity, consequently the area also varies as the square root of the absolute temperature, so that the formula for the air horse-power may be written thus:

$$\text{A. H. P.} = \frac{5{\cdot}2 \times P \times V \times \sqrt{\dfrac{t_1 + 461}{t + 461}} \times A\sqrt{\dfrac{t_1 + 461}{t + 461}}}{33{,}000}$$

where V and A are the velocity and area at the temperature corresponding to t.

Simplified, this becomes

$$\text{A. H. P.} = \frac{5 \cdot 2 \times P \times V \times A}{33{,}000} \times \frac{t_1 + 461}{t + 461}.$$

From the above, it will be evident that the horse-power varies as the absolute temperature, that is, if

$$P = A\,H\,P \text{ corresponding to } t$$
$$\text{and } P_1 = \quad ,, \qquad ,, \qquad ,, \; t_1,$$

then $$P_1 = P \times \frac{t_1 + 461}{t + 461}.$$

These formulæ do not take into account losses from leakage, but this question will be investigated in a future chapter.

CHAPTER III

CHIMNEYS

The chimney is by far the oldest form of apparatus used to produce a draught. Its properties have been known for many centuries, and, considering the importance of it, the astonishing thing is that so little trouble has been taken to thoroughly investigate the laws which govern its efficient design. Of late years more has been done in this way, but in earlier times chimneys were built very much on the rule-of-thumb principle. Their chief recommendations as a means of producing draught are their simplicity, reliability, freedom from any working parts, and also the low cost of maintenance when once erected. As everyone is aware, a chimney is simply a hollow column of masonry, or a steel tube, into which the hot gases from the boilers are conducted. The movement of the gases in the chimney is due to the fact that, as they are hot their weight is lighter than an equal volume of cold air. They are consequently overbalanced by the latter, and the want of equilibrium gives motion to the column of hot gases, which rises, and the cold air from outside flows through the fire with a certain velocity to take its place. This velocity depends on many things, and the most important are: height of chimney, average temperature of gases, and area of cross-section of the interior of the chimney.

Fig. 4 is a diagram showing the manner in which a chimney acts.

A is a column of cold air.

B is a column of hot air.

C is a fire.

As soon as the fire is lighted at *C*, the hot gases, given off by the burning fuel, ascend in *B*. Now the following action takes place. The column of cold air in *B* is heated, and, as the weight of air decreases with a rise of temperature, it follows that the column of air in *B* will become lighter than that in *C*. This results in motion being set up in the direction of the arrows, and in this way the fuel at *C* is continually supplied with the necessary oxygen to keep it alight, and in turn the column *B* is kept heated. In actual practice, the cold column of air is the atmosphere surrounding the chimney.

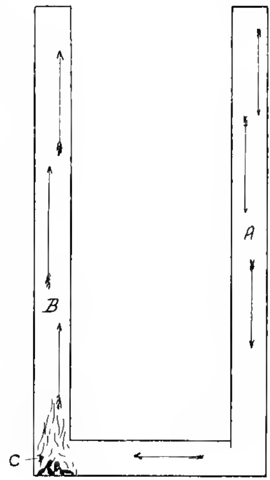


FIG. 4.

The velocity of gases in a chimney will be roughly proportional to the square root of the water-gauge. If the gases were able to pass up the chimney without any retarding effect due to friction on the inside surfaces, the velocity would be exactly proportional to the square root of the water-gauge, but as the air pressure increases so does the velocity, and consequently the friction. Therefore, in actual practice, it will be found that the velocity will increase at a somewhat lower rate.

In Chapter II. a Table was given of the velocity of air for different pressures. In ordinary chimney draught it will never be found that the actual velocity of the gases approaches that shown in the table. This is principally due to the friction of the gases, both upon the inside surface of the chimney and flue, and also on account of the resistance offered by the fuel. The loss in friction that would arise if the flues were constructed so as to require a velocity corresponding with the head, in order to get rid of the gases sufficiently quickly, would entail a heavy loss in air pressure in the chimney itself, and the fires would suffer accordingly from insufficient draught. All practical formulæ for obtaining the size of a chimney must necessarily be empirical, as it is absolutely impossible to calculate, with anything approaching certainty, what actual losses take place. Many engineers have devoted considerable time to the problem, and some of the more notable formulæ that have been devised are given below.

TABLE IV.

Authority.	Area square feet.	Height.
Molesworth .	$A = \dfrac{F}{12\sqrt{H}}$	$H = \left(\dfrac{F}{12A}\right)^2.$
Christie .	$A = \dfrac{F}{K\sqrt{H}}$	$H = \left(\dfrac{F}{KA}\right)^2.$
Gale . .	$A = 0{\cdot}07\,F^{\frac{1}{2}}$	$H = \dfrac{180}{t}\left(\dfrac{F}{G}\right)^2.$
Lange .	$A = 0{\cdot}00049\,B\,F$	$H = 15\,D + 32{\cdot}5.$
Smith . .	$A = \dfrac{0{\cdot}0825\,F}{\sqrt{H}}$	$H = \left(\dfrac{F}{12A}\right)^2.$

A = area at top in square feet (inside).
B = weight of air allowed per lb. of coal.
D = diameter at top in feet (inside).
F = weight of coal burnt per hour (lbs.).
G = grate area in square feet (total).
H = height of chimney above grate in feet.

$$K = \begin{cases} \dfrac{F}{1{\cdot}89\,G} & \text{for bituminous coal.} \\ \dfrac{F}{G} & \text{for anthracite.} \end{cases}$$

t = temperature of flue gas, deg F.

A rule that will be found to give good results may be stated as follows:—

Taking the average value for the velocity of the hot gases at 1000 feet per minute, through the net area of a chimney 100 feet high, then the velocity for other heights will vary as the square root of the height.

Let H = height of chimney above grate,
V = velocity per minute; then

$$V = 1{,}000\,\frac{\sqrt{H}}{\sqrt{100}}.$$
$$= 1{,}000 \times \frac{\sqrt{H}}{10}.$$
$$= 100 \times \sqrt{H}.$$

Thus, for a chimney 200 feet high, the velocity will be

$$V = 100\,\sqrt{200}.$$
$$= 100 \times 14{\cdot}14.$$
$$= 1414 \text{ feet per minute.}$$

In the above rule, by net area is meant the gross area less a strip 2 inches wide round the perimeter, so that in a circular chimney 5 feet in diameter the gross area is 19·6 square feet; therefore the net area will be that of

a circle 4 feet 8 inches diameter, that is, 17·6 square feet. It is upon this last figure that the velocity will have to be calculated.

The allowance of 2 inches is necessary, as it is found that the gases immediately adjacent to the brickwork are stationary, or move only very slowly; consequently this portion of the chimney is ineffective.

The following Table gives the maximum velocities of gases in feet per minute, which are recommended for chimneys of various heights. The velocities given should not be exceeded, but may with advantage be somewhat less.

TABLE V.

Height.	Velocity through Net Area.	Velocity through Gross Area. Diameter of Chimneys in Feet.				
		4.	6.	8.	10.	12.
70	836	702	745	767	781	795
80	894	752	797	820	834	850
90	948	796	845	870	885	901
100	1000	840	892	918	934	951
110	1048	880	935	962	978	996
120	1095	920	976	1005	1022	1041
130	1140	957	1017	1016	1064	1084
140	1183	994	1055	1085	1105	1125
150	1225	1029	1092	1124	1144	1164
160	1265	1062	1128	1161	1181	1203
180	1341	1126	1196	1231	1252	1275
200	1414	1487	1261	1298	1320	1344
220	1483	1245	1322	1361	1385	1410
240	1549	1301	1381	1421	1446	1473
260	1612	1354	1437	1479	1505	1533
280	1674	1406	1493	1536	1563	1591
300	1732	1454	1544	1589	1617	1647

When designing a chimney the principal data required will be :—

(1.) The maximum number of boilers it will serve.

(2.) Square feet of grate area per boiler.

(3.) Amount of coal to be burnt per square foot of grate.

It will first be necessary to determine the height required. For this the quantity of coal to be burnt per square foot of grate would have to be known. A simple rule given by Professor R. H. Thurston is that the amount of coal burnt per square foot of grate equals twice the square root of the height of the chimney, minus 1.

This, put in the form of an equation, is

$$F = 2\sqrt{H} - 1,$$

from which it is seen that

$$H = \left(\frac{F+1}{2}\right)^2,$$

where H = height of chimney in feet as before.

F = fuel in lbs. per square foot of grate.

Having ascertained the height, the next thing to obtain is the area, which will depend upon the height and the volume of gases to be dealt with. In the case of a well-arranged boiler plant, with all the brickwork of the flues in good condition, it will be necessary to allow 300 cubic feet of cold air at 32° F. per lb. of coal when the boilers are working under natural draught. Having obtained the total grate area, and the fuel burnt per square foot, it is an easy matter to get the total coal burnt per hour. Allowing the above quantity of air per lb. of coal, the total quantity of cold air per hour or per minute is easily arrived at. The volume of air thus

obtained must be corrected for the mean temperature in the chimney, which, in a well-designed plant, will usually be about 550° F. Roughly, the temperature in a brick chimney is reduced about 2° F. for every yard in height, so that if the gases at the base are at a certain temperature (T_b), the temperature at the top (T_t) will be

$$T_t = T_b - \frac{H}{3} \times 2,$$

and the mean temperature will be

$$T_m = \frac{T_b + T_b}{2}.$$

This may be simplified, so as to save the double operation, into

$$T_m = 2\,T_b - \left(\frac{H}{3} \times 2\right)$$

$$= T_b - \frac{H}{3},$$

where

T_b = temperature at base of chimney,
T_t = temperature at top of chimney,
T_m = mean temperature of chimney,
H = height of chimney in feet.

The following example has been worked out to illustrate the foregoing rules :—

It is desired to build a chimney suitable for a battery of seven Lancashire boilers. The grate area per boiler is 39 square feet, and the fuel is to be burnt at the rate of 25 lbs. per square foot of grate per hour. Assume that the temperature of the gases as they enter the base is 600° F. From the formula given above, the height of the chimney necessary to burn the fuel at the rate specified may be calculated thus :

$$H = \left(\frac{25 + 1}{2}\right)^2 = 13^2 = 169 \text{ feet, say } 170 \text{ feet.}$$

The mean temperature of the gases in the chimney will be

$$T'_m = 600 - \frac{170}{3}$$
$$= 600 - 56{\cdot}6$$
$$= 543{\cdot}4^\circ \text{ F., say } 544^\circ \text{ F.}$$

It is now necessary to determine the total weight of fuel that will be burnt per hour.

There are seven boilers each with a grate surface of 39 square feet. The total grate area (G) is

$$G = 39 \times 7$$
$$= 273 \text{ square feet.}$$

Let $F' =$ the total weight of fuel burnt per hour, then

$$F' = 273 \times 25 = 6825.$$

This is equivalent to 113·75 lbs. of coal per minute. If 300 cubic feet of air at 32° F. are allowed per lb. of coal, then

$$\text{Total air} = 113{\cdot}75 \times 300$$
$$= 34{,}125 \text{ cubic feet per minute.}$$

This air, when converted into gases, at the mean temperature of the inside of the chimney, will occupy a much greater volume than at 32° F. These gases may be treated exactly as if the original air were heated to the temperature of the chimney, ignoring the fact that it has undergone a chemical change. This may be done without introducing any appreciable error. It has already been mentioned that this increase in volume is proportional to the absolute temperature, therefore

the volume of the gases at the higher temperature will be

$$\text{Volume at } 544^\circ \text{ F.} = 34{,}125 \times \frac{544 + 461}{32 + 461}$$

$$= 34{,}125 \times \frac{1{,}005}{493}$$

$$= 69{,}560 \text{ cubic feet.}$$

The velocity of the gases per minute inside the chimney will be

$$V = 100 \times \sqrt{170}$$

$$= 100 \times 13{\cdot}05 = 1{,}305 \text{ feet.}$$

The effective area of the chimney will be

$$A_e = \frac{69{,}560}{1{,}305} = 53{\cdot}4 \text{ square feet.}$$

If a circular chimney is to be built, the actual internal diameter will be 8 feet 7 inches, after making due allowance for the ineffective belt of gases immediately adjacent to the brickwork. The length of a side of a square chimney, required to give the necessary area, would be 7 feet 5 inches.

Chimneys that are designed in accordance with the above rules will be found to agree very closely with many that are already satisfactorily at work; in fact these formulæ have been constructed from actual examples which have been brought under the writer's notice, and they constitute a mean of the values that have been observed. Few formulæ are in entire agreement as to the height and area of chimneys. Readers who are interested enough in the subject to trouble about it will find a most instructive exercise in the calculation of these dimensions from the formulæ given in Table IV., and will notice how the values vary.

It will be seen that the method just described gives a greater area than any except the second one, namely, that given by Lange, while it gives a greater height than any except the formula devised by Professor Gale.

There are several tables of chimney dimensions given in various publications, but almost invariably the area is too small when considered in the light of the rules just given.

When designing a new chimney, it will be necessary to estimate the approximate suction water-guage pressure that it will produce. Commence by finding the static pressure due to the two columns of air, at the temperatures of the atmosphere, and of the gases in the chimney interior. Thus there is the column of air outside, at a density which will be denoted by d_1 while d_2 will represent that of the column of hot gases inside the chimney.

Let H = the height of the chimney in feet,

P = static pressure in pounds per square foot,

then $P = H d_1 - H d_2$

$= H (d_1 - d_2)$.

Now refer to the example which has already been worked out, where the height is 170 feet and the mean temperature of the gases 544° F., and assume that the temperature of the atmosphere is 50° F. It is known that air at 32° F. has a density of ·0807 lbs. per cubic foot, therefore the density at 50° F. is

$$d_1 = \cdot 0807 \times \frac{32 + 461}{50 + 461}$$

$$= \cdot 0778 \text{ lbs.},$$

and similarly at 544° F. it will be found to have a density of ·0396 pounds per cubic foot.

By substituting these values in the above equation it is found that

$$
\begin{aligned}
p &= 170\ (\cdot0778 - \cdot0369) \\
&= 170 \times \cdot0382 \\
&= 6\cdot494 \text{ lbs.}
\end{aligned}
$$

It has been shown that a pressure of 1 inch of water is equivalent to 5·2 lbs. per square foot, therefore, under the above temperature conditions, the static pressure in inches of water at the base of the chimney would be

$$
\begin{aligned}
P &= 1 \times \frac{6\cdot494}{5\cdot2} \\
&= 1\cdot25 \text{ inches.}
\end{aligned}
$$

As soon as the gases are set in motion, the water-gauge pressure will fall considerably. The following formula will give the probable suction pressure likely to be obtained in practice under normal conditions :

$$
P = H\left(\frac{7\cdot6}{t} - \frac{7\cdot9}{T}\right)
$$

where T = absolute temperature of gases at base of chimney

t = absolute temperature of atmosphere.

Substituting the actual values, it is seen that

$$
\begin{aligned}
P &= 170\left(\frac{7\cdot6}{50 + 461} - \frac{7\cdot9}{600 + 461}\right) \\
&= 170\left(\frac{7\cdot6}{511} - \frac{7\cdot9}{1061}\right) \\
&= 170\ (\cdot01487 - \cdot00745) \\
&= 170 \times \cdot00742 \\
&= 1\cdot26 \text{ inches.}
\end{aligned}
$$

If the mean temperature is taken, instead of the temperature at the base, the result becomes $P = 1\cdot19$ inches.

This is nearer to the actual draught that the chimney

will give than the former figures. One must not rely too much upon the results of the formulæ for the suction water-gauge, for however carefully data of chimney draught are taken, the formulæ devised therefrom can only be correct for weather conditions similar to those that existed when the observations were made. Alterations in the temperature and humidity of the atmosphere, or the force and direction of the wind, all tend to cause variations in the intensity of the draught. The condition of the inside of the chimney will also affect the result. The following table gives the pressure in inches of water that may be expected with the temperature of the atmosphere at 32° F. and of the gases at 600° F. at the base of the chimney.

TABLE VI.

Height of Chimney.	Mean Temperature.	Draught: Inches of Water.
70	577	0·54
80	574	0·62
90	570	0·7
100	567	0·78
110	564	0·84
120	560	0·92
130	557	1·00
140	554	1·08
150	550	1·14
160	547	1·22
180	540	1·37
200	534	1·5
220	526	1·63
240	520	1·77
260	514	1·89
280	507	2·04
300	500	2·16

It may happen sometimes that a chimney which is already in existence does not give sufficient draught. It is necessary to warn readers not to be led into supposing that an increase in the height will necessarily give the draught required, otherwise they may be tempted to go to a considerable expense with disappointing results. Should the draught be poor, it must be ascertained, in the first place, if the chimney is of sufficient area to take the gases which will be produced by the increased rate of combustion. If this point is not accurately decided the expense and trouble of an alteration may be entirely thrown away. The reason is that, although an increase in the height will certainly tend to increase the water-gauge, it must be remembered that the several resistances of the flues and chimney will increase as the square of the velocity, so that the added resistances of these will tend to nullify the effect which the increased height of the chimney should have on the fires. If the chimney is of ample area, then the additional height will have an appreciable effect on the furnaces. An example of an actual chimney, which is at present working satisfactorily, may not be without interest to readers. It is therefore given below with the data collected while under normal working conditions. The particulars are :—

Height of chimney 157 feet above grate.
Area „ „ 81 square feet.
Temperature at base 400° F.
Total coal burnt per hour 10,521 lbs.
Water-gauge at base 0·5 inches.

Coal burnt per minute $\frac{10,521}{60}$

$= 175{\cdot}3$ lbs.

If 250 cubic feet are allowed per lb. of coal consumed, then the cold air required at 32° F. per minute is:

$$\text{Air per minute} = 175{\cdot}3 \times 250$$
$$= 43{,}825 \text{ cubic feet,}$$

and the volume of this air, when raised to 400° F., will be

$$43{,}825 \times \frac{861}{493}$$
$$= 76{,}538 \text{ cubic feet.}$$

If 20 per cent. is added to this, to cover waste and leakage, which will be a sufficient allowance, as the boiler plant in question is in excellent condition, then the total volume of gases to be dealt with will be:

$$\text{Total volume of gases} = 76{,}538 + \left(76{,}538 \times \frac{20}{100}\right)$$
$$= 91{,}845.$$

As the area of the chimney is 81 square feet, the velocity through the gross area is:

$$\text{Velocity of gases} = \frac{91{,}845}{81}$$
$$= 1{,}134 \text{ ft. per minute.}$$

This will be seen to agree fairly closely with the velocities given in Table V. The diameter of a chimney with an area of 81 square feet will be rather more than 10 feet. On looking down the table it is seen that for a chimney 10 feet diameter and 160 feet high the velocity of gases may be 1,181 feet per minute.

CHAPTER IV

CONSTRUCTION

Factory chimneys are usually built of brick, but of late years steel has come very much into vogue. A chimney built of the latter material, that is steel, is considerably less expensive, but the life of it cannot be nearly so long as a well-designed one built of brick. Up to the present time steel chimneys have not been long enough in general use to enable one to say what their average life is, but it is unlikely to be of more than twenty years duration.

Brick chimneys are either circular, square, or octagonal in shape, but of the three a circular one is to be preferred, on account of the lower wind resistance it offers. A very neat and workmanlike looking chimney is built by making the lower portion square, and then continuing with a shaft circular in shape. The height of the square part should be about one sixth of the total height. It is essential that a chimney should have a very substantial foundation, as the total weight of a large factory chimney is very great. This should be made of concrete, and the building of the shaft should not be commenced until it has had at least a month to set hard. Under these conditions, the area of foundation allowed should be such that the pressure does not exceed four tons per square foot. The depth depends entirely upon the nature of the ground, but it should be carried down until good sound foundation is reached. Where this is not possible piles

must be driven to secure the requisite solidity. Too much care cannot be taken to see that this foundation is built upon a really firm base. It is quite possible, after an apparently solid strata has been reached, that it rests upon a substratum of much less stable material. Should this be so, there is the possibility that as soon as the weight of the chimney is placed upon it the foundation will move. Some guide as to the necessary area to allow for foundations will be got from the following.

If the ground upon which the chimney is to be built is "made" ground the pressure should not exceed one ton per square surface foot, that is, the pressure should be reckoned upon the area of the foundation at the surface of the ground. If the ground is of a clayey nature two tons may be allowed as a maximum, and from three to eight tons if of rock.

The external dimensions of the chimney next claim attention. Molesworth says that the diameter at the base should be not less than one tenth of the height, also that the outside batter should be 0·3 inch per foot, and that the thickness of the brickwork should be one brick for 25 feet down, one and a half bricks for 25 to 50 feet from the top, and so on.

If the inside diameter at the top exceeds 4 feet, then the thickness must be one and a half bricks instead of one, but in the case of very small chimneys the first 10 feet may be only a half brick in thickness. A good quality of concrete should be used in the foundations, and in cases where a very expensive and consequently heavy chimney is to be built steel joists are often bedded into them, to aid in binding the whole together. After the lower portion of the foundation is got into place the upper part should be stepped back in 6-inch courses

as seen in the illustrations, as it is unnecessary to carry it up to the ground level to the full dimensions. When this work has been completed, and has had sufficient time to set properly, the building of the shaft may be commenced. Arrangements must be made for the entrance of the gases from the boilers. The openings provided for this purpose will detract from the strength of the structure, so that the brickwork surrounding them must be strong, the top being arched, and the corners finished off with bull-nosed bricks. Provision must also be made at the base, for a cleaning door to enable accumulations of soot being easily removed. This opening may be fitted with a hinged door if preferred, but, as the base of the chimney will require to be cleaned out only very infrequently, an iron plate bricked into place will suffice. If an iron door is decided upon, a cast-iron frame should be built into the chimney, also the door must be well fitted and quite air-tight. If the foundations have to be built in a water-laden soil, great care must be taken to keep the hole free from water, and while building operations are proceeding it may be necessary to keep a pump at work. The concrete should be made quickly, and rammed well after it is put in place.

In the best designs a factory chimney consists of two elements, namely an outer and an inner shaft. An air space is left between the inner surface of the outside shaft and the outer surface of the inner one. This annular space forms a good non-conducting medium and prevents the gases in the chimney becoming very much cooled. During the course of erection the two shafts will be bonded together at regular intervals. It is advisable to procure correctly shaped bricks, especially in the case of a circular chimney, as it will greatly add to

the appearance of the work, and will obviate a considerable amount of labour in the actual work of erection. Cement mortar should be used, as it is preferable to lime for this work. Some designers prefer to line the inside of the chimney with firebrick, but this is quite unnecessary, if the temperature of the gases is not likely to exceed 600° F., and if the material used for the inner shaft is a good quality of well burned brick. The chimney may be finished off with a cap of a more or less ornamental design, carried out either in brickwork or in cast-iron, depending upon the class of ornamentation desired, and

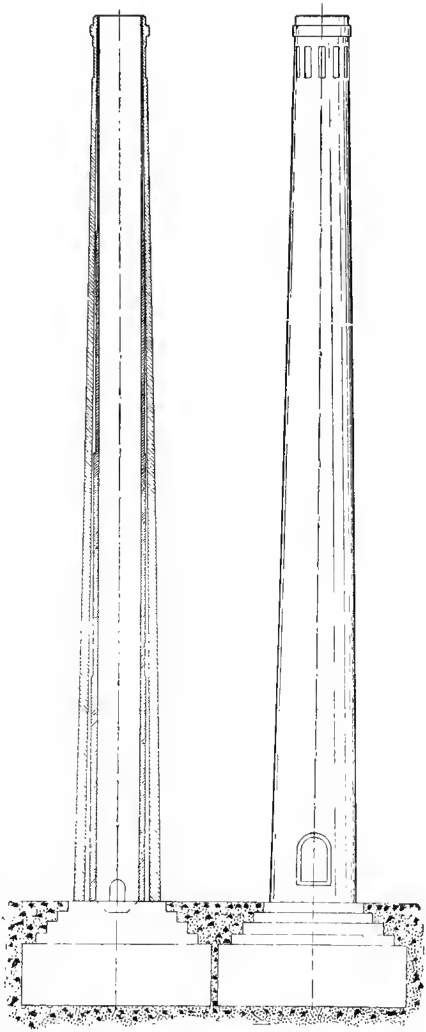


FIG. 5.

also upon the expense to which the owners will agree. If a cast-iron cap is decided upon, it is well to design it so that the centre of gravity of a section on one side of the centre line lies inside the diameter of the chimney.

An example of a brick chimney is seen in Fig. 5.

When, as is frequently the case, two flues enter the chimney at opposite sides, a mid fin should be built

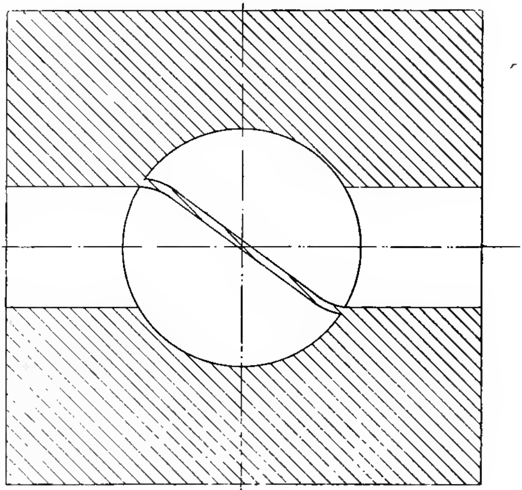


FIG. 6.

across the shaft, as shown in the section through the lower portion of a chimney, see Fig. 6.

If this is not done, the draught will be greatly impaired.

It is only in first-class work that separate shafts are built, which leave an annular space between as seen in Fig. 5, but for chimneys of moderate size it is usual to build only a single shaft.

If a steel chimney is desired, the foundation will be very similar to that of a brick chimney, but a number of holding-down bolts will have to be built into it. These will be placed in a circle, the diameter of the pitch line being made to correspond with the holding-down flange at the base of the shaft. These bolts should be spaced about 1 foot 6 inches to 2 feet apart, this distance depending upon the size of the chimney and the diameter of the bolts. The foundation should be carried up just level with the ground line, and the chimney mounted immediately upon it, or else, if desired, a short square-brick column may first be built, and the chimney bolted to this. If the first method is employed, the entrance through which the gases reach the chimney must be arranged for in the foundation. If the second style is preferred, this entrance may be in the column of brick-work immediately above the foundation, but this is a matter of convenience.

The foundation should be finished with a heavy cast-iron ring, secured by means of the holding-down bolts mentioned above, and upon this ring the chimney proper must be erected. The plates of which it is built should vary in thickness, the lower rings being about $\frac{1}{2}$ inch to $\frac{9}{16}$ inch thick, while the upper ones may be only $\frac{3}{16}$ or $\frac{1}{4}$ inch thick. In shape this steel shell may be simply a straight cylindrical tube, in which case it will have to be provided with guy-ropes to maintain it securely in a perpendicular position. These guy-ropes must each be fitted with turn buckles, to allow of correct adjustment.

If the chimney is to be a self-sustaining one, the lower portion should be coned, as seen in Fig. 7. Let D represent the diameter of the outside of the steel chimney, if it were

continued to the foundations in the same manner as one that is kept in position with guy-ropes, then the diameter of the base should be $2D$ and the height of the cone from $3D$ to $4D$. If a square concrete foundation is provided, the length of any side of the base should also be from about $3D$ to $4D$, depending upon the nature of the ground and the height of the structure. This form of steel chimney takes up less room than the one first described, as there is no necessity for guy-ropes. It also has a very neat appearance.

Ornamental cornices are sometimes fitted, in which case copper is found to be the best material for these, as it resists corrosion. At the best of times ornamentation is expensive and also a very dissatisfactory way of employing capital. It also gives a very top-heavy appearance to a chimney, in the writer's opinion.

For the construction of a steel chimney, no rivets less than $\frac{7}{16}$ inch diameter should be employed. Where the plates used are more than $\frac{7}{16}$ inch thick, then the rivets in these plates should be the same in diameter as the plates are in thickness.

The steel shell must be lined completely with brickwork to the top, otherwise the excessive cooling effect, due to the greatly increased conductivity of steel over brickwork, will so reduce the temperature of the gases as to greatly impair the draught. This is particularly noticeable in wet and windy weather. A case in point occurred only recently in the writer's experience. A municipal electricity works had erected a steel chimney, which proved unsatisfactory, so they proceeded to line it throughout, and although this greatly reduced the effective area, and consequently increased the velocity of the gases, yet, notwithstanding, the draught was enormously

increased, and the chimney afterwards gave complete satisfaction.

A space is usually left between the lining and the steel shell, which space may be filled up with dry sand if preferred. The weight of a steel column is very much less than a brick one for a given duty, weighing often only about one-third.

When a steel chimney is being erected it should be painted inside and out with a paint made of red lead and linseed oil. The inside should receive two coats and the outside three, and every two years afterwards it should be given outside one coat of a similar paint.

Fig. 7 is an illustration of a steel chimney. A portion of a boiler plant intimately connected with the chimney is that of the flues. These are the brickwork passages along which the gases flow from the boiler on their way to the chimney. They should be of ample area, and if possible should not include in their construction any sharp bends. Wherever it is necessary to alter the course of the gases, it should be done as gradually as circumstances will permit. It is well to allow sufficient area of cross-section, so as to ensure that the velocity of the gases will not exceed 1,500 feet per minute, but it may with advantage be less. In this way the loss in friction will be minimised, and the full effectiveness of the chimney obtained. In the event of mechanical draught being used, generous flue proportions lower the horse-power that is required to drive the fan. This is on account of the decreased air pressure that will have to be employed. If it is necessary to enlarge the flue at any point, as may happen should an economiser have to be installed, then this enlargement must be gradual. In the same way, when the flue has to be reduced, after

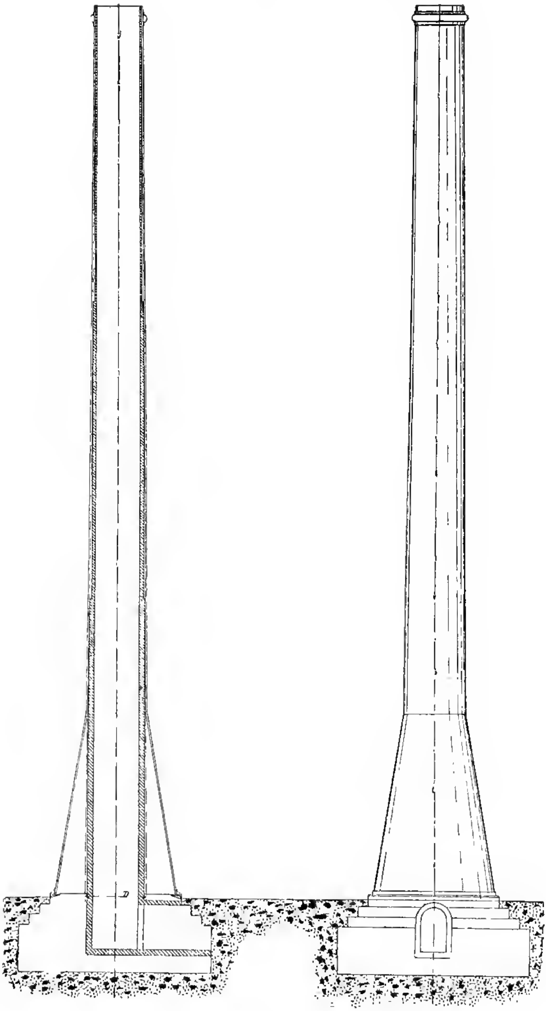


FIG. 7.

the gases leave the economiser, this again must not be accomplished suddenly. Abrupt alterations in the cross-sectional area of a flue cause losses, through the eddy currents that are set up, hence the necessity of attending to this point. When the flues from several boilers discharge into one main flue, it is advisable to fit curved guide plates in such a way that the individual streams of gases will not impinge directly upon the main current. An example is seen in Fig. 8.

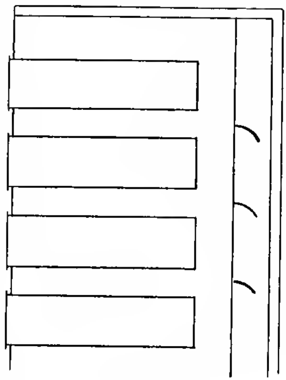


FIG. 8.

Attention to such points as these will ensure the highest efficiency being obtained, and is especially worth while where natural draught is employed, as in the best of installations from 18 to 20 per cent. of the total heat of the fuel is required to produce the draught. It therefore behoves owners of factories to make the best use of this expensive portion of their plant.

The flues should be lined throughout with firebrick, and the joints between the bricks made with good fire-clay mortar and kept as thin as possible. Specially shaped firebricks are to be obtained for the settings of boilers.

Flues must never be so contracted that they will not leave room for a man to enter for the purpose of inspection, or for the periodical removal of soot. A cast-iron door and frame should be built into the outer wall of the flue at some convenient spot to admit of access to the interior.

The dampers, which will be fitted at various points in the flues, should be of the butterfly type, and preferably provided with cast-iron frames. These dampers are carried upon a spindle fixed at the vertical axis of the actual damper plate. They are therefore balanced and are easily opened and closed by means of a handle which is fitted to an extension of the spindle that projects through the brickwork of the flue. This class of damper is preferable to those which open and close by sliding vertically in a frame, and are raised or lowered by means of a chain attached to them which passes over pulleys. The other end of the chain is provided with weights to balance that of the damper. These dampers entail the use of this cumbrous gear, but a worse feature is that a considerable amount of leakage takes place at the slot in the iron frame, or brickwork, through which the damper plate passes. When forced draught is employed this leakage allows a quantity of waste gases to escape into the boiler-house, but with natural or induced draught more work is put upon the chimney or fan, whichever happens to be employed. Some advantage will be gained if flues are regularly cleared of soot. The periods for doing this should be arranged so that there is no chance of the flues becoming unduly choked. The length of time that may elapse between each cleaning will have to be fixed for each individual plant, and will depend upon the amount of work it has to do, the class of fuel used, the degree of perfection that is attained in the combustion of the fuel, and other such details.

Of recent years ferro-concrete has been used occasionally in the construction of chimneys. It has the advantage of being much lighter than brick, as usually employed.

A form of chimney known as the "Monoshaft" has a distinctly neat appearance. This is a patented design, and the name of the patentee is M. Monnoyer.

The chimney is constructed of specially shaped blocks of concrete, which are made in a mould, and are formed with a claw at one end, in such a way that the plain end of the next block fits into it. The outside of a claw comes at each angle of the chimney and forms an effective rib, giving the completed structure a very good appearance. The vertical reinforcements are placed in the spaces which the claws form, and after they are in position semi-dry concrete is used to cement the whole into one solid mass. The blocks are formed with a groove along the top surface, and in this is laid the horizontal reinforcing member, which latter is securely fixed to the vertical reinforcements. A certain amount of taper can be given to the shaft, the magnitude of which depends upon the distance each block is inserted into the claw of the one preceding it.

CHAPTER V

ARTIFICIAL DRAUGHT

ALTHOUGH chimneys possess the advantage that after they are once built the maintenance charges are very light, and also that there is little to go wrong with them, they have their limitations and disadvantages, which are:—

1. They are affected badly by climatic conditions.
2. The draught is limited by their height and area.
3. The intensity of the draught is not readily controllable.
4. The efficiency is very low.
5. The first cost is very high.

Many systems have been devised for overcoming these disadvantages, and they may be placed under the general head of artificial draught. This again is properly subdivided into two systems, viz.:—

1. Jet-controlled draught.
2. Mechanical draught.

Under the first section comes the steam jet placed in the chimney, as commonly seen in locomotive practice, and the steam for this jet is supplied by the exhaust from the cylinders. This was a very general practice at one time in the case of factory chimneys, but it is almost obsolete now, as far better uses can be found for the exhaust steam. This system is still to be seen in some places, and can generally be detected by the very jerky

manner in which the smoke issues from the top of the chimney. It is only for locomotives that it is extensively employed at the present time, and in this case it is almost, if not quite, a universal practice. It is scarcely too much to say that if it had not been for the steam jet induced draught the problem of rapid transit, as it is known to-day on railways, would at least have been far more difficult to solve, and quite probably would never

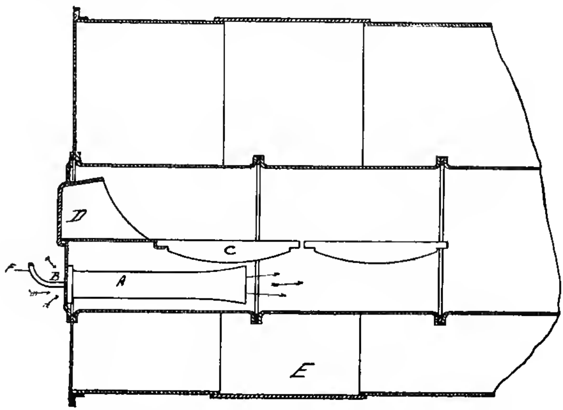


FIG. 9.

have been solved at all, so that in this particular instance a good use is made of steam which would otherwise go to waste.

Of the many different attempts made to employ steam-jets for the production of draught, probably the best known device is the Meldrum forced draught furnace. The application of this, as many readers will know, consists of entirely closing up the ashpits of boilers of the Lancashire or Cornish type. These are then fitted with cast-iron tubes of a special form, in the centre of which a small steam jet is fixed. The steam when

turned on induces a strong current of air to flow through these cast-iron tubes, and this air is delivered into the ash-pit under pressure, and thence is forced through the boiler fires. The intensity of the draught may be regulated by adjusting the steam supply to the jet. In Fig. 9 is seen a section through a furnace fitted with one of these appliances.

A is the cast-iron specially shaped tube.

B is the steam jet.

C are fire-bars.

D is the furnace front.

E is the boiler shell.

F is the steam supply pipe.

There are many other systems in which the steam jet is employed. In some the fire-bars are perforated and hollow, and the jets are applied through the centre of the bars. It would take up too much space to enumerate all the different systems, but some of the more important will be described in a further chapter.

Great care must be exercised when selecting a system of draught. It is not advisable to use steam jets in any form if the fuel contains much sulphur, because this, along with the moisture supplied by the steam, produces sulphuric and sulphurous acids. These afterwards condense and settle in the cooler portions of the boiler, or on the economiser tubes, and cause bad corrosion. Also when a steam jet is employed for forced draught the steam, on passing through the fuel, takes up some of the heat, which in other systems would be used for generating steam in the boiler. This class of apparatus has the advantage, however, that the initial cost of installing it is low in comparison with other methods.

The draught is limited in a chimney by its dimensions,

and in any case it is not practicable to build it of a height that will give such an intense draught as is possible with some forms of mechanical apparatus. One reason is the greatly increased expense of a very tall chimney, and another is that the mean temperature in the chimney will be lowered, and consequently the increase of the draught will not be proportional to the increased height but somewhat less. For instance, it has already been seen that the mean temperature in a chimney 170 feet high, with a temperature of 600° F. at the base, is about 544° F. Assuming that the rate of heat loss due to radiation, etc., remains the same, the mean temperature in a chimney 300 feet high will be

$$\begin{aligned} T_m &= 600 - \frac{300}{3} \\ &= 600 - 100 \\ &= 500^\circ \text{ F.} \end{aligned}$$

In actual practice it will be found that it is rather higher than this, as the rate at which the gases lose their heat will probably be slightly less towards the top, because the temperature difference between the gases and the atmosphere is less at the greater height.

A further disadvantage of a high chimney is that the interest on capital outlay and a certain charge for depreciation, say $2\frac{1}{2}$ per cent., has to be met each year, and this alone on a large chimney would amount to a considerable sum. Then again, the intensity of the draught, even within the limits of a chimney, is not easily controllable. It is dependent upon the adjustment of heavy and inconvenient dampers, and at the best only a very approximate regulation can be attempted. The inefficiency of a chimney is well known, but many owners are willing to countenance it, partly because of the simplicity

of this means of producing a draught, and also because of the entire absence of any need of attention beyond the adjustment of the dampers, and probably because they are quite unaware of the extent of the loss which is entailed by the use of it. This matter is dealt with more closely in a future chapter, but it may be noted here that if a chimney is to work at its highest efficiency it should be dealing with gases at a temperature of 550° to 600° F. Professor W. J. M. Rankine, in his classical work on the steam engine, says that the weight of gases discharged by a chimney is greatest when the ratio of the absolute temperature of the atmosphere to that of the gases in the chimney is as 12 is to 25, and under these conditions a great amount of heat goes to waste, so to prevent this other means of providing a draught have been devised. This brings the reader to the second section of boiler draught with which this chapter deals, viz., *Mechanical Draught*. Mechanical draught includes all systems in which a mechanically-driven fan is employed. Sometimes this fan is placed in the boiler-house, and the air from it forced along ducts into closed ash-pits, and thence through the fires. A system designed on those lines is known as *forced draught*. Another method is to place the fan at the base of the chimney so that it deals directly with the hot products of combustion, which latter method of application is known as *induced draught*. Both systems have their advantages and disadvantages. A forced draught fan usually deals with cold air, therefore less power is required to drive it than when an induced draught fan is employed, which latter deals with hot gases. On the other hand, forced draught has a tendency to blow holes in the fires, especially where the boilers are hand fired. On the whole, for land boilers an induced

draught plant is usually adopted, except in cases where forced draught is required in connection with some special type of furnace.

Where an induced draught plant is installed in connection with an economiser, the inlet of the fan should be connected to the flues between the economiser and the chimney. The fan will then have to deal with gases at about 350° F. instead of 550° to 600° F. There will thus be an advantage gained due to this reduction in temperature of the waste gases, which is that the power required to drive the fan will be considerably less. Another detail that must be given due consideration is the ratio of grate surface to heating surface. Before a mechanical draught system is installed a certain amount of fuel per square foot of grate would be consumed. If a plant is fixed to give a more intense draught, a greater amount of coal per square foot would be burnt, so that if no extra steam is required the grates may be much reduced in area. Another advantage of a more intense draught would be that much thicker fires could be used, so that the air required for combustion would come more intimately into contact with the fuel. Thus a much less quantity of oxygen would pass through the fires, uncombined with the carbon of the coal. As each lb. of carbon only requires a certain amount of oxygen, it is apparent that a much less weight of air per lb. of coal would be necessary. The result would be that the gases would reach a much higher temperature in the furnaces, and if the grate area remained the same the gases would leave the boiler at a higher temperature. If the most economical results are required this should not happen, and to prevent it some adjustment of the furnaces would be necessary to increase the ratio of grate

surface to heating surface, so that the temperature of the gases issuing from the boiler would remain the same.

A further economy may be obtained by installing apparatus for preheating the air as it goes into the boiler furnaces. This will abstract some of the heat still remaining in the products of combustion after they leave the economiser, and will further reduce the temperature of the gases which the fan has to handle. The Howden system of preheating air is probably the best known for forced draught installations, but this is principally used on board ship. The system invented by Messrs. Ellis & Eaves is often met with on land, in connection with induced draught. A very considerable gain in economy may easily be obtained in cases where the gases entering the preheater are at a temperature of 300° to 350° F. On account of the greatly improved combustion obtaining in plants where mechanical draught is installed much less smoke will be made, in fact, in some cases, only a very thin mist will be seen escaping from the chimney top.

When a completely new works is being built, a subject which continually presents itself for the consideration of the proprietors is capital expenditure. In most localities a minimum height is fixed by the authorities for factory chimneys. This is usually much too low to give the draught necessary for a modern boiler installation, the chimney of which would have to be built much higher. With mechanical draught the height need only be such as will satisfy local regulations. It sometimes happens that there is no need to build a chimney higher than is sufficient to take the products of combustion far enough into the atmosphere to prevent

them being an inconvenience about the actual premises. This will save the large initial expense of a tall factory chimney, which is very much more costly than is a mechanical draught plant.

When deciding upon the class of artificial draught that it will be best to employ two principal factors must be considered :

(1) Initial cost of plant.

(2) Economy of working.

Generally speaking, devices in which a steam jet is employed are, as already mentioned, much cheaper to instal than a mechanically-driven fan. On the other hand, they use considerably more steam, probably two or three times as much as a steam engine capable of driving the fan. Then again, the steam goes to waste and is not recoverable in any way. In the case of a steam-driven fan an altogether different condition of things exists, for the exhaust steam from the engine can be used for heating the feed water of the boiler, so that very little heat is wasted. The engine of a mechanically-driven draught plant requires only a very small proportion of the total steam generated, but the smaller the plant the greater is the proportion of the total steam required.

The combined efficiency of a steam-driven fan of moderate dimensions, that is, the ratio between the indicated horse-power of the engine and the air horse-power representing the output of the fan, should be about 65 per cent. From careful tests made some years ago by the writer to find out the efficiency that could be reckoned on where jets of steam were used to induce a flow of air, most disappointing results were obtained. It was found that an efficiency of only 10 to 15 per

cent. at the very outside was likely to be realised. These results were obtained by measuring the volume of air discharged and the air pressure, and also by measuring the weight of steam used. It was known what horse-power this steam would develop if used to drive an engine of a similar type to that which would be employed for mechanical draught, and so the efficiency was calculated on this basis. When economy in running costs is more to be desired than a minimum initial outlay, a mechanically-driven fan will be found the most suitable device to employ.

CHAPTER VI

FORCED DRAUGHT

It has already been stated that forced draught is the system almost universally employed on board ship, and Howden's special appliance is the one generally adopted.

In this system the air, on its way to the furnaces, is forced by a fan through a chamber attached to the boiler front. The hot gases, before passing up the funnel, are forced through tubes in this chamber, and so preheat the air. The advantage of this system is that combustion is more complete, and can be accomplished with a less quantity of air per lb. of coal than would be possible with natural draught, also some of the waste heat is retained by the preheating of the entering air. From both these causes higher furnace temperatures are obtained, and so greater economy in fuel results.

Often the stokehold is sealed, and the fans are fitted without a case in such a manner that they revolve just inside the bulkhead, causing a pressure of air to be maintained throughout the stokehold. In land boilers, when a forced draught system is employed, provision must be made for closing the ducts which lead the air to the ash-pits at the same time that the fire doors are opened, otherwise there is the danger that the fire will blow back into the stoker's face and cause a nasty burn. An arrangement is often fitted so that the action of opening the door closes a butterfly damper fixed in the

air duct. This obviates any danger from the above cause, making it impossible for any accident to happen should the stoker neglect to close the damper, which might easily occur in a moment of forgetfulness if it were not connected permanently to the furnace door.

It is necessary to so arrange the furnace fronts that some air can be discharged above the fuel to assist the combustion of the volatile hydrocarbons which are given off as each fresh charge of coal is thrown on the fires. If this is not done trouble will arise on account of the emission of heavy smoke from the chimney.

When it is desired to apply forced draught to an existing plant, consisting of water-tube boilers, it will generally be found most convenient to build a brick duct along the front of the boilers, the top of which can be formed of well-fitting chequer plates. From this main duct passages should be built to convey the air to the several boilers, which passages should be fitted with dampers for regulating the supply of air independently to each furnace. In the case of Lancashire or Cornish boilers the ash-pits should be sealed, and the air led below the fire-bars by means of steel-plate ducts. When a new set of water-tube boilers is being installed the bridge may be built hollow to form the main duct, and this is then fitted with dampers, which are controlled from the boiler fronts by long levers. The discharge from these ducts should not be directed towards the fire-bars, but the dampers should be so arranged that they act as a baffle and spread the air over the floor of the ashpit before it ascends through the fires. This is a very important point in the arrangement of forced draught, which, if not attended to, will lead to the uneven combustion of the fuel, so that the fire will tend to burn

into holes. Should this happen, a quantity of cold air will find its way into the furnace, which will cool the gases and decrease the efficiency of the boiler. When this system is applied to the furnaces of Lancashire boilers, it is usual to fit baffle plates, arranged so as to prevent the current of the blast being directed locally upon the fuel. The fan for creating the draught may be driven in any way that is most convenient. The writer prefers a steam engine for the motive power, because if this is used a special regulating valve can be employed which is controlled by the steam pressure in the boilers. With this arrangement the speed of the fan will vary with the demands made upon the boilers, so that the steam pressure can be kept constant.

The next questions that arise are, what quantity of air will be required for a certain consumption of fuel, the power necessary to move this air, and also the diameter and speed of the fan to do the work?

With regard to the amount of air that is required for combustion, the theoretical quantity that is necessary for an average lb. of coal is approximately 12 lbs., that is, 150 cubic feet of air at 32° F., but in actual practice a much greater allowance is made. For a first-class plant in which the draught is furnished by means of a chimney usually about twice the amount is required, and it would be by no means difficult to find cases in which 350 to 400 cubic feet of air per lb. of coal is used. Such conditions, of course, are extremely wasteful. The difference between the amount of air used and that theoretically required for combustion is known as the air required for dilution, and, as seen above, may easily vary from 100 to 200 per cent. more than the theoretical requirements. In a modern plant, where everything is

kept up in good condition, and where some system of mechanical draught is employed, it will usually be found that from 200 to 250 cubic feet per lb. of fuel will be sufficient. This reduction is greatly due to the fact that a much more intense draught is employed, which enables fires of a greater thickness to be worked, and, as the air pressure is entirely controllable, it can be regulated to suit the greater resistance caused by the thick fires. Under these conditions, it will be seen that each particle of air becomes more intimately mixed with the carbon in the fuel, so that much less oxygen will pass through uncombined with the carbon. It is therefore obvious that a much less weight of air will be necessary to supply the requisite oxygen, so that the gases leaving the fuel, which are approximately equal in weight to the air entering it, will be at a greatly increased temperature. One reason why this is so is very obvious. The atmosphere consists of 21 parts of oxygen to 79 of nitrogen, which latter gas is absolutely useless for purposes of combustion. It therefore passes through the fuel not only uselessly, but it is actually detrimental, because a considerable amount of the heat units obtained from the coal is taken up by the nitrogen in order to raise its temperature to that of the gases, thus reducing the furnace temperature. It is therefore quite clear that if it is possible to reduce this loss the temperature of the gases in the furnace will be much higher, and, as the amount of heat transmitted to the water through a metal plate is directly proportional to the difference in temperature on the two sides, it follows that the evaporative power of a boiler will therefore be increased. Thus, although the gases in the furnace are hotter, they ought not to escape from the boiler into the flues at a

higher temperature, otherwise the full advantage due to mechanical draught is lost. It will therefore often be necessary to make an alteration to the area of the grate, as already suggested.

If the main object is to obtain a greater quantity of steam, it may not be possible to manage this without sacrificing the steaming capacity which the fan was principally intended to augment. It occurs not infrequently that a battery of boilers is in such a restricted space that it is not possible, in cases where there is a scarcity of steam, to instal another boiler. In such an instance, a well-proportioned forced draught plant may quite easily be the means of generating 30 per cent. more steam, and, at the same time, doing this more economically, that is, evaporating a greater weight of water per lb. of fuel.

If it is not convenient to alter the grate area, the economiser, if one is fitted, can be increased by adding more tubes to it, and thereby raising the temperature of the feed water. In Chapter II. was given the method of calculating the horse-power represented by the movement of a known volume of air against a resistance. The formula for this is

$$A\,H\,P = \frac{5{\cdot}2 \times P \times V \times O}{33{,}000}$$

where V and O represent, respectively, velocity of air per minute and area of orifice in square feet. It is easily seen, therefore, that these multiplied together give the volume passing through the fan.

Let $V \times O =$ volume $= x$.

This simplifies the formula into

$$A\,H\,P = \frac{5{\cdot}2 \times P \times x}{33{,}000}.$$

This does not take into account the loss of power in the fan itself which will vary depending upon the efficiency of the plant. With a fan of moderate dimensions, say one capable of dealing with 60,000 cubic feet of air per minute at a pressure of 2 inches of water, there should be no difficulty in obtaining an efficiency of 70 per cent., therefore if

$$B\ H\ P = \text{brake horse-power}$$

$$n = \text{efficiency,}$$

then $$B\ H\ P = \frac{5{\cdot}2 \times P \times x}{33{,}000 \times n}.$$

In order to eliminate intermediate calculations and so facilitate the obtaining of the brake horse-power directly from the weight of coal burnt, it is necessary to fix upon a certain volume of air per lb. of fuel. This must be estimated from a knowledge of the boiler plant to which it is to be fitted.

The formula for the brake horse-power then becomes

$$B\ H\ P = \frac{5{\cdot}2 \times P \times F \times x_1}{33{,}000 \times n},$$

where F = weight of coal in lbs. per minute

x_1 = volume of air in cubic feet per lb. of F.

By making

$$\frac{5{\cdot}2 \times x_1}{33{,}000 \times n} = \text{a constant} = K$$

then $B\ H\ P = K \times P \times F$.

The following table gives K for different values of x_1 and n.

TABLE VII.

n.	x_1.				
	150	200	250	300	350
0·3	·07875	·105	·13125	·1575	·18375
0·4	·05895	·0786	·09825	·1179	·13755
0·5	·04725	·063	·07875	·0945	·11025
0·6	·03937	·0525	·06562	·07875	·09187
0·7	·03375	·045	·05625	·0675	·07875
0·8	·02953	·0394	·04922	·05907	·06892
0·9	·02625	·035	·04375	·0525	·06125

To find the speed of the fan in revolutions per minute it is first necessary to ascertain what air pressure will be required to overcome the resistance of the fires, flues, and chimney, and also to give the air the necessary velocity. Usually a pressure of 2 to $2\frac{1}{2}$ inches of water is sufficient, but in cases where the flues and chimney are very small, or where the gases have to be forced along tortuous passages with sharp corners, the air pressure must be increased. Experience, and a careful inspection of the boiler plant, to which the appliance is to be fitted, is necessary before a final decision can be arrived at. When the requisite air pressure has been decided upon, the equivalent head can easily be calculated, as explained in a previous chapter. Then the linear speed of the periphery of the fan in feet per second is

$$V_f = a \sqrt{2\ g\ h},$$

where a is a constant depending on the shape of the fan blades. This constant will be greater than unity for cases in which the shape of the fan-blade tip is curved

backwards, that is, away from the direction of rotation, but it will be less than unity if curved in the opposite direction. For a perfectly radial blade only the constant is unity. In general calculations it may be taken at this last value, so that the speed of the fan in revolutions per minute will be

$$S = \frac{\sqrt{2\,g\,h} \times 60}{\pi\,d}$$

where d = diameter of fan in feet.

This may be simplified into

$$S = \frac{152{\cdot}7 \times \sqrt{h}}{d}.$$

The dimensions of the fan depend upon several things. In the first place, the method of driving has to be taken into account, as this more or less decides the speed at which it can be run, and which in turn will control the diameter. Then the volume of air which it has to handle must be considered, in order to arrive both at the width and area of inlet. In fact, one of the first things to ascertain is the diameter of the inlet, otherwise it is quite conceivable that the diameter of a fan suitable for a high speed might be arranged for, when the diameter of the inlet might be afterwards found to be greater than that of the fan. These things are matters which it is better to allow the makers of fans to settle, because it is very unwise for purchasers to interfere with these details. Naturally, manufacturers know best what their particular type of fan is most capable of doing.

In order to assist possible purchasers of a fan to arrive at the approximate over-all dimensions, the following will be found useful. First of all, it is necessary to decide upon the water-gauge pressure required. From this can

be found the velocity of the air due to the head, to which this is equivalent. Then, having obtained the volume of air which the fan is required to pass per minute, the area of the inlet is

$$O = \frac{x}{8\sqrt{h} \times 60 \times 0{\cdot}62}$$

$$= \frac{x_1 \times F}{8\sqrt{h} \times 60 \times 0{\cdot}62}.$$

The constant 0·62 is the co-efficient of efflux for a circular hole in a thin plate, which takes into account the reduction in the effective area due to the *vena contracta* and frictional losses.

Let d_i = diameter of inlet

then $d_i = \sqrt{\frac{4}{\pi} \times O}$

making d = diameter of fan as before.

Then the diameter of the fan impellor will be

$$d = d_i \times 1{\cdot}667.$$

In ordinary practice it will be found that a well-designed fan usually empties itself about twice for each revolution, so that the volume passed per revolution is

$$x_r = \frac{x}{s}$$

where x_r = volume discharged per revolution. On the assumption that the fan empties itself twice per revolution, it will be seen that the cubic capacity of the fan will be

$$M = \frac{x}{2\ s}$$

where M = capacity of fan in cubic feet.

If Z = width of fan then it is seen that

$$Z = \frac{\frac{x}{2\,s}}{\frac{\pi}{4}d^2}$$

$$= \frac{\frac{x}{2\,s} \times \frac{\pi}{4}}{d^2}$$

$$= \frac{0{\cdot}637\,\frac{x}{s}}{d^2}$$

which, in terms of the fuel burnt per minute, becomes

$$Z = \frac{0{\cdot}637 \times \frac{x_1 \times F}{s}}{d^2}$$

It will be an advantage at this point to work out an example based upon the formulæ just given. Take the data given in Chapter III., in which case there were seven boilers burning 113·75 lbs. of coal per minute with chimney draught, and requiring 300 cubic feet of air per lb. of coal. With forced draught this will be reduced to, say, 225 cubic feet per lb of fuel. Assume an air pressure of 2½ inches of water and a fan efficiency of 70 per cent. First of all, it is necessary to find the power that will be required, which from the formula is

$$B\,H\,P = \frac{5{\cdot}2 \times 2{\cdot}5 \times 113{\cdot}75 \times 225}{33{,}000 \times 0{\cdot}7}$$

$$= 14.4.$$

The head (h) in feet, which is equivalent to an air pressure of 2½ inches of water, is

$$h = \frac{62{\cdot}418 \times 2{\cdot}5}{12 \times {\cdot}0807}$$

$$= 161 \text{ feet at } 32^\circ \text{ F.},$$

and the area of the inlet will be

$$O = \frac{113 \cdot 75 \times 225}{8 \sqrt{161} \times 60 \times 0 \cdot 62}$$

$$= 6 \cdot 79 \text{ square feet,}$$

from which the diameter will be found to be

$$d_i = \sqrt{6 \cdot 79 \times \frac{4}{\pi}}$$

$$= 2 \cdot 94 \text{ feet,}$$

and the diameter of the fan impellor is thus

$$d = 2 \cdot 94 \times 1 \cdot 667$$

$$= 4 \cdot 9 \text{ feet.}$$

It is now necessary to determine the speed of the fan in revolutions per minute. As already explained, this can be calculated as follows :—

$$S = \frac{\sqrt{(2 \times 32 \cdot 16 \times 161)} \times 60}{\pi \times 4 \cdot 9}$$

$$= 397 \text{ revolutions per minute.}$$

The only dimension that remains to be found is the width of the fan impellor. This is seen to be

$$Z = \frac{0 \cdot 637 \times \dfrac{225 \times 113 \cdot 75}{397}}{4 \cdot 9^2}$$

$$= 1 \cdot 71 \text{ feet, or, say, 1 foot 9 inches.}$$

These figures are for use if the constant for the blade shape is unity. If it varies from this, both the diameter and the width of the fan will be modified. The exact value of the constant can only be determined by carefui experiment.

CHAPTER VII

INDUCED DRAUGHT

It has already been cursorily mentioned that an induced draught plant consists of a fan placed at the base of the chimney, and connected with a battery of boilers. Its function is to draw the hot gases from the flues and discharge them into the chimney. The action of the fan draught upon the fires is exactly similar to that of a chimney, only that it can be much more intense, and, like forced draught, it is controllable at will, and is quite independent of climatic conditions. One great advantage of this system is that there is no danger of accidents from burns, the tendency being for the fan to draw the air through the fire doors, as soon as they are opened. However, a disadvantage under which it labours is that the power required to drive the plant is considerably more than that necessary for forced draught. But as a set-off against this is the fact that the cost of installing an induced draught plant is usually considerably less than for forced draught. This is because in most cases there is not a great amount of air duct to be arranged for, the suction of the fan being merely coupled up to the existing flues, and the discharge connected to the chimney by a short piece of steel tubing or a brickwork passage.

Peclèt tried an experiment with induced draught some years ago, when he had two boilers constructed which were arranged so that one could be worked with natural

draught. This was fitted with a furnace in the usual way. The second boiler, having no furnace, was installed as an auxiliary to the first, but in the outlet for the gases was fitted an induced draught plant. Dampers were provided in this experimental installation, and were so arranged that the gases from the first boiler could be drawn through the second one, by the induced draught

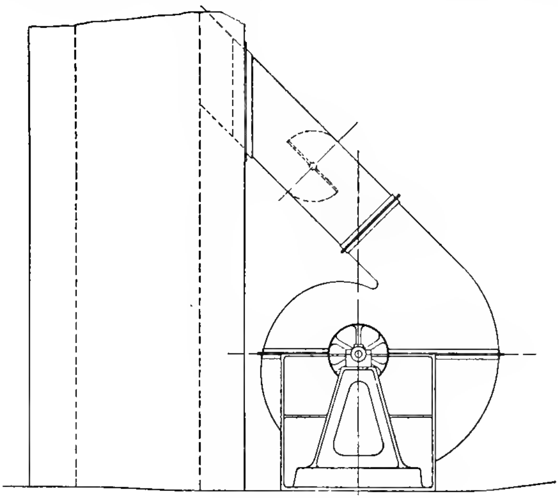


FIG. 10.

fan. He obtained very favourable results, finding that about 25 per cent. more coal could be burnt per square foot of grate, while more than 50 per cent. additional steam was generated. With natural draught he evaporated 7·21 lbs. of water per lb. of coal, while with mechanical draught the evaporation was 9·26 lbs. In the former case, the temperature of the waste gases was 650° F., while in the latter it was only 410° F. This difference of 240° represents about 57 British

thermal units saved per lb. of gases. When designing a plant of this description, it should, if possible, be arranged so that the discharge is in an upward direction as seen in Fig. 10. This reduces the resistance offered to the flow of the gases.

It is easily seen that if the gases were discharged horizontally into the chimney they would impinge against

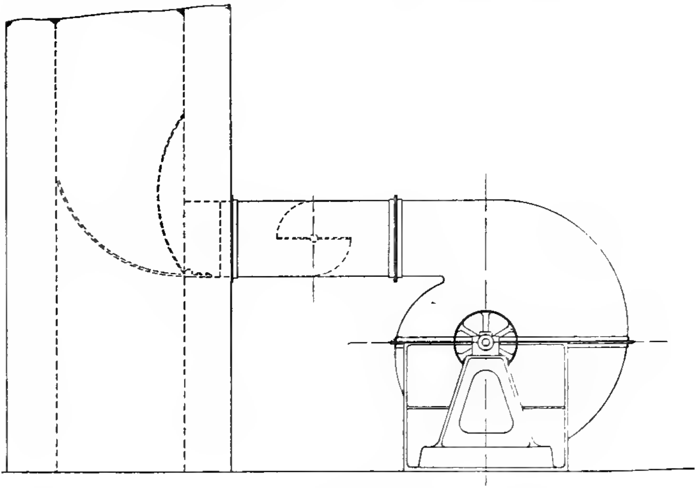


FIG. 11.

the opposite wall, which would prevent them getting freely away. This would cause an obstruction, and so reduce the output of the fan. When a horizontal discharge is unavoidable, a curved plate should be fitted to guide the air into an upward direction. If it is sometimes desired to use the chimney instead of the fan, the curved plate can be hinged, so that it may be raised or lowered at will, as shown in the illustration in Fig. 11.

It is likewise inadvisable for the fan to be arranged so

as to discharge the gases in a downward direction, and should be avoided wherever possible. The natural tendency of the hot gases is to rise, but if they are constrained to go downward, it will be necessary to provide additional driving power for the fan, in order to overcome the greater resistance.

It has been shown that the power required to drive a correctly designed fan is proportional to the absolute temperature of the air with which it has to deal. It is therefore important, in order to reduce the power to the lowest point, that the temperature of the gases should be as low as possible. Therefore, where an economiser is installed, the fan should deal with the gases after they leave it. It will usually be found that at this point they will be at a temperature of 350° to 400° F. It may sometimes happen that it is not possible to get a fan in this position, and so the next best place is to fix it between the boiler and economiser, where the temperature of the gases will be about 600° F. This will entail a certain amount of additional power as already mentioned.

An important point to notice in the case of an induced draught plant is that of leakage. Where forced draught is used this matter is unimportant, as any leakage that takes place will be that of gases from the inside of the flues, and will not put additional work on the fan. With induced draught the case is entirely different. As there is a higher air pressure outside the boiler flues, settings, etc., than inside, any leakage that there is will therefore be into the flues. Consequently, a fan must be so proportioned that it will deal with this leakage, in addition to the gases generated by the combustion of the fuel. Even in a boiler plant, where everything is in good condition, this leakage may easily amount to 25 per cent.

of the total air required for combustion, and is the sum of the leakages through damper fittings, flues, man-hole lids, being principally due to the porosity of the bricks and mortar. This allowance of 25 per cent. also covers the extra weight of gases, over and above the weight of air entering the fire. For instance, if a boiler is using 24 lbs. of air per lb. of fuel burnt, and this fuel contains 80 per cent. of combustible matter, it is obvious that the gases generated will weigh 24 + ·8 = 24·8 lbs. for every lb. of coal burnt, that is, an increase of 3·3 per cent., leaving a balance to cover actual leakage of 21·7 per cent.

To prevent leakage through brickwork, the writer finds that if it is painted with several coats of gas tar, a decided reduction in the amount of leakage will be noticeable; but it will be reduced to a minimum, if the boiler settings are faced with glazed bricks, and care is taken to see that the mortar joints are kept as thin as possible. All brickwork inside the boilers should be kept in good repair, and frequently inspected with this end in view.

When making calculations for an induced draught plant the necessary allowances must be made for leakages and temperature of gases. Otherwise the fan will give very disappointing results. Using the same symbols as for forced draught, the horse-power in the air becomes

$$A\,H\,P = \frac{5{\cdot}2 \times P \times V \times A}{33{,}000} \times \frac{t_1 + 461}{t + 461}.$$

This can be simplified, as before, into

$$A\,H\,P = \frac{5{\cdot}2 \times P \times x}{33{,}000} \times \frac{t_1 + 461}{t + 461}.$$

Let n = fan efficiency, then

$$B\,H\,P = \frac{5{\cdot}2 \times P \times x}{33{,}000 \times n} \times \frac{t_1 + 461}{t + 461}.$$

This formula may be modified, to enable one to calculate the brake horse-power directly from the fuel, as in the case of forced draught.

Let k = percentage of leakage

x_1 = cubic feet of air per lb. of fuel.

F = fuel burnt in lbs. per minute.

Then

$$B\,H\,P = \frac{5{\cdot}2 \times P \times (F + k\,F) \times x_1}{33{,}000 \times n} \times \frac{t_1 + 461}{t + 461}.$$

The calculations necessary for arriving at the dimensions of the fan are very similar to those for forced draught. The periphery speed of the fan will vary as the square root of the head, as in the case of a forced draught plant, so that the formula

$$V_f = a\sqrt{2\,gh}$$

remains as before. The value of $\sqrt{h}$, of course, varies as the density of the air, which is considerably less for hot air than for cold. The higher temperatures that are usual with induced draught, therefore, require the periphery speed of the fan to be greater. This speed in revolutions per minute is as before.

$$S = \frac{a\sqrt{2\,g\,h} \times 60}{\pi\,d}$$

where d = diameter of fan in feet.

The area of the fan inlet is the next point of importance. This will be also found as in the previous chapter, viz.:

$$O = \frac{x}{\sqrt{2\,g\,h} \times 60 \times 0{\cdot}62} \times \frac{t_1 + 461}{t + 461}.$$

The head (h) will, in this case, be a very much greater

figure than when cold air is being employed. The above formula becomes in terms of fuel burnt

$$O = \frac{x_1 \times (F + k\ F)}{\sqrt{2\ g\ h} \times 60 \times 0{\cdot}62} \times \frac{t_1 + 461}{t + 461}$$

from which the diameter is easily found.

If d = diameter of fan, then for an induced draught fan

$$d = d_i \times 1{\cdot}67.$$

This will give a good proportion, and the width of the fan will be

$$Z = \frac{\dfrac{x}{2\ s}}{\dfrac{\pi}{4}\ d^2},$$

and this, in terms of the fuel burnt per minute, is

$$Z = \frac{0{\cdot}637 \times \dfrac{x_1 \times (F + k\ F)}{s} \times \dfrac{t_1 + 461}{t + 461}}{d^2}.$$

Now apply the foregoing to the supposititious case already mentioned. Assuming that the same amount of air per lb. of coal is required, and that the leakage into the flues is 25 per cent. of the total air necessary, then $k = 0{\cdot}25$.

Also assume that the waste gases enter the fan at 350° F., then the brake horse-power required is

$$B\ H\ P = \frac{5{\cdot}2 \times 2{\cdot}5 \times (113{\cdot}75 + (0{\cdot}25 \times 113{\cdot}75) \times 225}{33{,}000 \times 0{\cdot}7} \times \frac{350 + 461}{32 + 461}$$

$$= \frac{5{\cdot}2 \times 2{\cdot}5 \times 142 \times 225}{33{,}000 \times 0{\cdot}7} \times \frac{811}{493}$$

$$= 29{\cdot}5.$$

A cubic foot of air at 350° F. weighs

$$W_1 = 0{\cdot}0807 \times \frac{32 + 461}{350 + 461}$$
$$= 0{\cdot}049,$$

so that the head (h) is

$$h = \frac{62{\cdot}418 \times 2{\cdot}5}{12 \times {\cdot}049}$$
$$= 266 \text{ ft.}$$

From this the area of the inlet will be

$$O = \frac{225 \left\{ 113{\cdot}75 + (0{\cdot}25 \times 113{\cdot}75) \right\}}{\sqrt{2 \times 32{\cdot}16 \times 266} \times 60 \times 0{\cdot}62} \times \frac{811}{493}$$
$$= 10{\cdot}78 \text{ square feet.}$$

therefore, the diameter of the inlet is

$$d_i = \sqrt{10{\cdot}78 \times \frac{4}{\pi}}$$
$$= 3{\cdot}7 \text{ feet.}$$

The diameter of the fan impellor will then be

$$d = 3{\cdot}7 \times 1{\cdot}667 = 6{\cdot}17 \text{ feet.}$$

The speed of the fan must next be determined, and will be

$$S = \frac{1 \sqrt{2 \times 32{\cdot}16 \times 266} \times 60}{\pi \times 6{\cdot}17} = 406 \text{ revolutions}$$

per minute, and the width of the fan will be

$$Z = \frac{0{\cdot}637 \times \dfrac{225 \left\{ 113{\cdot}75 + (0{\cdot}25 \times 113{\cdot}75) \right\}}{406} \times \dfrac{811}{493}}{6{\cdot}172}$$

$$= 2{\cdot}167 \text{ feet, say, 2 feet 2 inches.}$$

CHAPTER VIII

A COMPARISON

Now that examples of the three principal methods of producing a draught for factory boilers have been worked out, a comparison of the results obtained may be interesting. This will be made upon a heat unit basis. As most readers are aware, a British Thermal Unit is the amount of heat that is required to raise 1 lb. of water 1° F. in temperature. The specific heat of a substance is the amount of heat that is required to raise 1 lb. of it 1° F. in temperature. Now the specific heat of air is 0·236, which means that it requires 0·236 B. Th. U. to raise the temperature of 1 lb. 1° F.

In the first place, it will be noted that the temperature at the base of the chimney with natural draught is 600° F., while with mechanical draught it is only 350° F. Then the total volume of the gases is 34,125 cubic feet per minute at 32° F., as seen in the example on page 27. Now the weight of this air is:

$$\text{Weight of air} = \frac{34{,}125}{12{\cdot}36} = 2{,}760 \text{ lbs.}$$

It has been seen that in order to obtain a good draught it is necessary in the case of a chimney that the gases should be at about 600° F., that is 250° F. higher in temperature than is found in the examples of mechanical draught.

The amount of heat that will be necessary to raise the temperature of the above weight of air to 600° F. is :

$$\text{B. Th. U.} = 2{,}760 \times (600-32) \times 0{\cdot}236$$
$$= 370{,}000 \text{ per minute about.}$$

With forced draught the volume of air required per minute was 25,600 cubic feet, that is :

$$\text{Weight of air} = \frac{25{,}600}{12{\cdot}36} = 2{,}071 \text{ lbs.}$$

In this case the temperature at the base of the chimney is 350° F., so that the heat units which escape with the gases are :

$$\text{B. Th. U.} = 2{,}071 \times (350-32)\ 0{\cdot}236$$
$$= 155{,}000 \text{ about.}$$

An induced draught plant requires the same amount of air per lb. of coal as a forced draught plant, in so far as the actual combustion is concerned. To this must be added the amount of air that is anticipated will leak into the flues. In the example taken this has been estimated at 25 per cent., so that with this plant the total heat units will be :

$$\text{B. Th. U.} = 155{,}000 \times (0{\cdot}25 \times 155{,}000)$$
$$= 193{,}750 \text{ about.}$$

It is seen that the saving in heat units by employing induced draught is therefore :

$$\text{Saving in B. Th. U.} = 370{,}000 - 193{,}750 = 176{,}250$$

In the example worked out it was seen that although the temperature at the base of the chimney was 600° F., the mean temperature in the chimney was 544° F., therefore the number of heat units lost in radiation is

$$\text{B. Th. U.} = 2{,}760 \times (600 - 544) \times 0{\cdot}236$$
$$= 36{,}400$$

so that the net heat units used solely for creating a draught will be

$$\text{Net B. Th. U.} = 370{,}000 - 36{,}400 = 333{,}600$$

In Table VIII. these figures have been collected together for convenience.

TABLE VIII.

Class of Draught.	Net B. Th. U.	Gain in B. Th. U. over Chimney.	Percentage Saving.
Chimney . .	333,600	—	—
Forced . .	155,000	178,600	53·6 %
Induced . .	193,750	139,850	42·0 %

These examples have been worked out so as to show clearly in what direction a saving may be expected. The figures obtained would be modified in practice by radiation and other losses. For instance, although in the case of induced draught it is seen that 139,850 units less escape to the chimney than with natural draught, not all this heat is available for use with economisers or feed heaters, but a portion will be given up to the feed water to raise its temperature. Much of it will be lost by radiation, both through the brickwork of the flues and also through the metal of the economiser tubes, and in other ways. What proportion actually is lost depends upon the condition of the installation to which it is applied. A considerable amount of the heat will be given up to the water in the boiler, and will thus directly generate additional steam. In the examples the amount of coal per minute has been constant, but the air per lb. of coal is considerably less in the case of mechanical draught. Now it has already been mentioned that this will raise the temperature of the gases in the furnace, and if the

grate area has been adjusted so as to bring the temperature of the escaping gases to about 600° F., then under these conditions it will be obvious that much more water per lb. of coal should be evaporated. It is on this account, and to the fact that the temperature of the escaping gases may be made lower, that the increased economy is greatly due.

It is generally found, when the conditions are favourable, that the application of mechanical draught will increase the steaming capacity of a boiler plant from 20 to 30 per cent., and this often with a cheaper quality of fuel. If the fan used is driven by a steam engine the amount of steam required by it is from 1 to $1\frac{1}{2}$ per cent. of the total steam generated by the boilers. A well-known firm of high repute, who have studied closely the problem of mechanical draught, recently fitted an induced draught plant to a battery of six Lancashire boilers. After the alteration these boilers easily did the work which formerly nine boilers could only do with difficulty in adverse climatic conditions, and not only so, but the extra duty was accomplished with an inferior fuel. The saving to the firm who purchased the plant was about £150 a month, and the initial cost of the installation was approximately only £550.

Fig. 12 is a diagram showing roughly the distribution of temperatures in a Lancashire boiler.

Case (1) is for a plant worked under natural draught conditions, and is shown by the full line.

Case (2) is for mechanical draught, in conjunction with which an economiser is at work, and is shown by the dotted line.

The vertical ordinate in the figure represents temperature in degrees Fahrenheit to scale, and the two curves

show diagrammatically where the variations in temperature occur. This has been fully explained in the preceding paragraphs.

Some years ago Mr. Arthur Blechyden read a paper before the Institute of Mechanical Engineers, in which he said, referring to Mechanical Draught:—

"First, it seems fairly well established that if the boilers are well constructed, and are provided with ample room to ensure circulation, their steaming power may

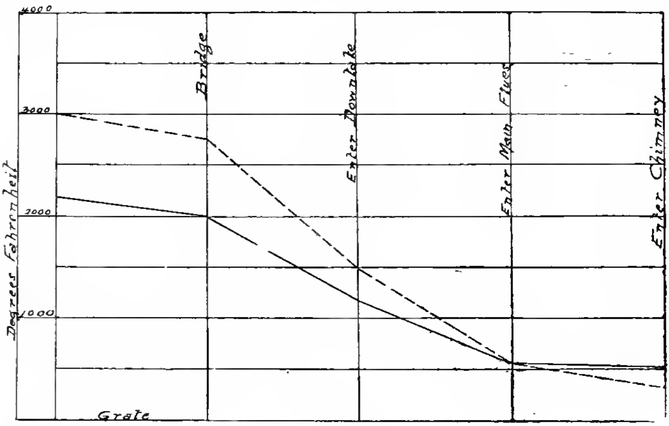


FIG. 12.

without injury be increased to about 30 to 40 per cent. over that obtained on natural draught for continuous working, and may be about doubled for short runs. Secondly, such augmentation is accompanied in normal cases by an increased consumption per indicated horse-power. But thirdly, the same or even greater power being indicated, it may with moderate assistance of forced draught be developed with a smaller expenditure of fuel, the grates, etc., being properly proportioned. Fourthly, forced draught enables an inferior fuel to be

used; and fifthly, under certain conditions of weather, when with normal proportions of boiler it would be impossible to maintain steam with natural draught, the normal power may with forced draught be ensured. In particular cases any or all of these advantages may be a source of economy; and the first of them may render possible that which would otherwise be impracticable."

The above quotation specially refers to forced draught in marine practice, but it may all be as truly said with regard to forced or induced draught for land installations.

The next question that arises is that of initial cost. A well-built chimney of the aforementioned dimensions, that is, 170 feet high and 8 feet 7 inches in diameter, would not cost less than £1,200 to £1,500. A forced draught plant suitable for seven Lancashire boilers, including a well-made enclosed high-speed engine, all necessary ducts and dampers, with automatic arrangements for closing the ducts as the boiler doors are opened, would cost approximately only £450, while the cost of an induced draught plant (provided that there were no long ducts, or ducts of a difficult shape to construct) would be about £350. In all cases these prices have been calculated on the assumption that first-class work has been employed, and the necessary foundation work has been allowed for. No chimneys have been included in the estimates for mechanical draught, but where these are necessary they will be much shorter, and also less in diameter than for natural draught, an allowance of £300 for them being ample. These values are only very approximate, and will necessarily vary according to the state of trade, value of materials, or locality. At the same time they may be taken as showing the relative cost of the several systems.

CHAPTER IX

THE APPLICATION OF MECHANICAL DRAUGHT FOR LAND INSTALLATIONS

Amongst the different systems that have been devised for the production of draught and the economical combustion of fuel, the following have been selected as representative arrangements, which have been successful in practice.

In Chapter VI. the Meldrum furnace was described. This belongs to that class of apparatus, which depends on a jet of steam for obtaining the necessary draught, and very considerable economy is obtained by its use.

A more elaborate furnace, but one that depends upon a similar arrangement of steam jets for its draught, is the Halliwell furnace. This is seen in Fig. 13, which shows some fire-bars in position, and also the special air tubes. There is nothing novel in the manner of creating the draught. The ash-pits are closed by a plate, and steam jets are fitted much in the same way as in the Meldrum furnace, but here the similarity ends. Immediately inside the ash-pits, opposite the steam jets and running parallel to the axis of the boiler are two tubes, which are made the same length as the furnace. The air induced by the jets is delivered into these tubes, and can only escape through the slots provided for it. These, it will be seen, are situated exactly opposite the spaces in the fire-bars. By this means the air pressure is

distributed evenly over the whole furnace, which is clearly shown in the illustration. It will be noticed that the fire-bars are placed across the diameter of the furnace, bearers being provided down each side. This arrangement is different to the usual practice, in which the spaces are parallel with the length of the furnace.

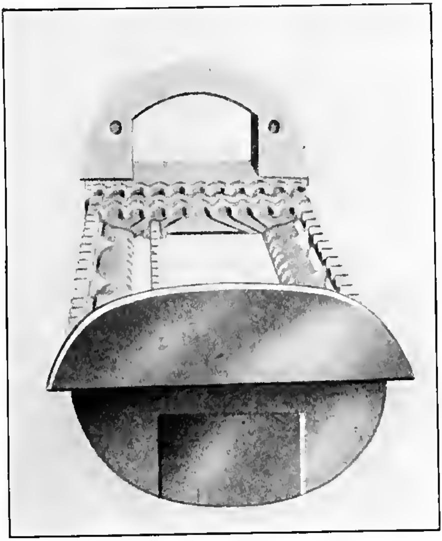


FIG. 13.

Another point of interest is that the bars are given a slight rocking motion, in order to break up clinker and to dislodge anything that gets between them, so as to prevent the air passages becoming choked up. The bars are specially shaped so as to prevent warping. The steam jets may, with advantage, be replaced with fan draught; and more economical results will be obtained on account

of the higher efficiency of the latter appliance, but, of course, the cost of the installation will be greater.

Another form of boiler furnace, designed to obtain economical combustion, and at the same time smokelessness, is that made by the well-known firm of E. Bennis & Co., Ltd. Each complete furnace equipment consists of a hopper, into which coal may be thrown by hand, or supplied by a system of conveying apparatus. Below this hopper is constructed a cast-iron feeding box, inside which is fixed a plate termed a "pusher plate." It is designed to have a reciprocating motion, which can be adjusted to suit the load on the boiler. The fuel falls from the hopper in front of this pusher plate, and is forced over a ledge formed by the bottom of the feeding box. An adjustable cam is fitted upon the driving shaft by which the rate of feed can be regulated while the apparatus is in motion. By observing the position of this cam, it may be noted what amount of fuel is being used. After the fuel is pushed over the ledge in the feeding box it falls on to the flat plate, which the makers term the "shovel box." Inside this a mechanically-operated shovel works which scatters the fuel that has already fallen upon the shovel plate into the furnace proper. The mechanism which works this shovel gear is interesting, and consists of a cylinder in which is fitted a piston. On one side of the piston a long coiled spring is placed, and is so arranged that the action of the cam compresses the spring, and upon being released forces the shovel smartly forward, thus scattering the fuel over the fire. To prevent any jar on the furnace front the opposite end of the cylinder from which the spring is placed, forms a pneumatic buffer, which takes up any shock and ensures quiet operation. Another point

of interest is the cam that works the shovel. There are four projections upon it, each one having a different lift so as to vary the force with which the fuel is projected forwards. By this arrangement the coal will be thrown to four different distances along the furnace, so that green fuel will only be upon one quarter of the fire at once, the remaining three-quarters being at different degrees of incandescence. This is a great aid to the smokeless combustion of the fuel, as the furnace is not chilled suddenly, but an even temperature is maintained which ensures the combustion of the volatile hydrocarbons. This furnace works under forced draught, which is also obtained by employing steam jets. The fire-bars are specially designed and consist of troughs which have a circular end to them. The fourth side of the troughs, viz., the upper one, is formed by the fire-bars proper, so that the troughs are protected from the fierce heat of the fire. The circular ends of these are at the front of the furnace, where each one is provided with a fine jet, through which highly superheated steam flows. This induces a current of air into each furnace trough at a high velocity, and from here it forces it way through the fire-bars into the fuel. The intensity of the draught can be regulated at will by varying the supply of steam to the jets. Another feature of this furnace is the moving fire-bars, which are drawn in and out by means of cams fixed upon a transverse shaft placed across the boiler fronts. This action results in the fuel being gradually forced to the back of the furnace, so that by this time nothing but clinker and ashes remain, which fall over the end of the furnace into a closed chamber between it and the brickwork bridge. The interior of this chamber is reached by

means of a swing door, which is controlled from the boiler front by a chain. This chamber should be

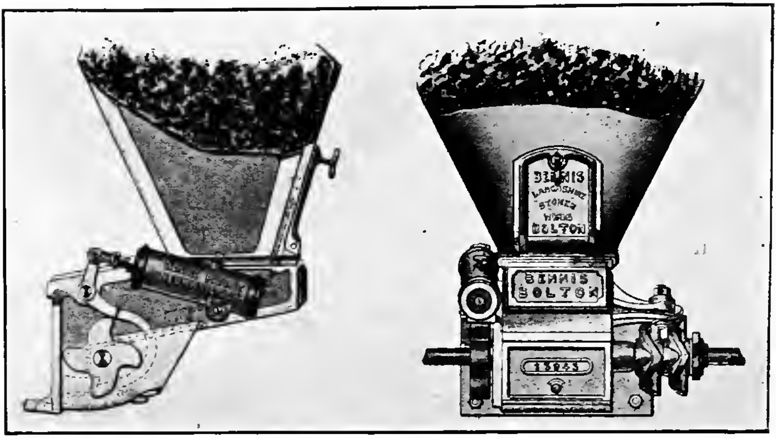


Fig. 14.

cleared periodically. Figs. 14 and 15 show the stoker and fire-bar arrangement.

Figure 16 is an illustration of a battery of three Lancashire boilers fitted with a simple forced draught

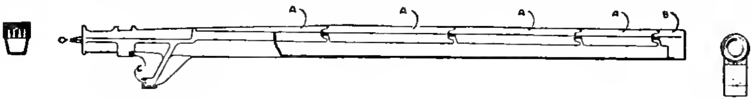


Fig. 15.

plant. The fan in this case is driven by a steam engine. It will be seen that the main duct is fixed below the floor level, and from it are taken the branches through which the air supply to the boilers is forced.

Air-valves are fixed in these branches, and may either be controlled by hand or may be arranged to close as the fire doors are opened, which has already been explained. In the illustration

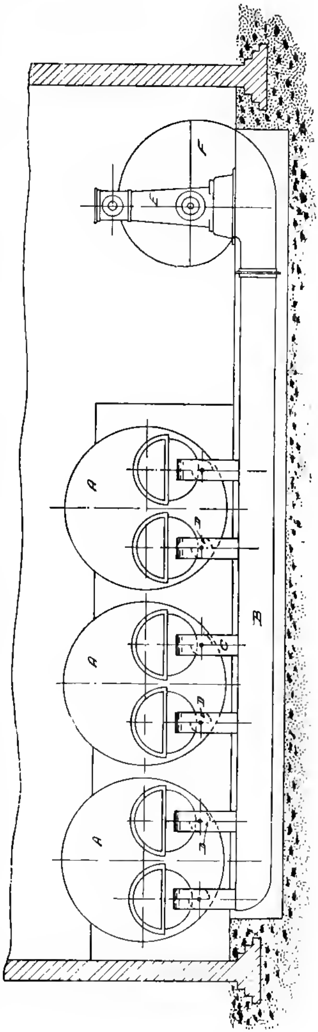


FIG. 16.

A A A are the boilers.

B is the main duct.

C is one of the branch ducts.

D are dampers.

E is the engine.

F is the fan.

A boiler furnace that has come very much to the fore of late years is that made by the Underfeed Stoker Company, Limited. There are several forms of this apparatus, but the principle employed in each is the same. It is a forced draught system. In the first place, the fuel is fed either by conveying machinery or by hand into a hopper on the boiler front. From here it is forced by mechanism into a trough or deep channel, which runs down

the centre of the furnace. The grate proper commences at the edge of the trough, and the mechanism employed forces the coal over the sides of it, and floods the grate. Before this happens the green fuel has already been coked in the trough, which is practically a retort, and the volatile gases given off are forced to pass through the bed of incandescent fuel immediately above it. In this way smokeless combustion is ensured.

The following description of a stoker, which the makers call their "Class E" design, will better enable the reader to understand the exact manner in which they work. The stoker is illustrated in Figs. 17 and 18. In these the fuel hopper is seen at *A* and the trough or retort at *V*. The mechanism is actuated by a steam motor *C*, which consists of a cylinder, and inside this a piston reciprocates. The amount of fuel that is fed into the furnace is controlled by the number of strokes made by this piston, and can be varied between wide limits. To the piston rod is attached a crosshead *D*, which is in turn bolted to the sliding bottom *E* of the trough, and which extends the full length of it. The block *B* which regulates the feed of fuel on to the sliding bottom *E* is attached to it, and thus has the same motion as *C* and *E*. When the apparatus is started *E* is drawn back, and at the same time the block *B* opens the hopper. The motion of the piston is then reversed, and the coal that has fallen on to *E* is pushed forward. This motion not only carries the fuel along, but it also forces it upwards, when it is first of all coked, and the volatile gases given off are consumed by the incandescent fuel above it. Then as it is forced higher it eventually spills over the sides of the retort and spreads across the fire-bars. These latter are specially designed and are

also arranged so that every other one is movable. This movement is a transverse one, and varies from $\frac{1}{2}$ to

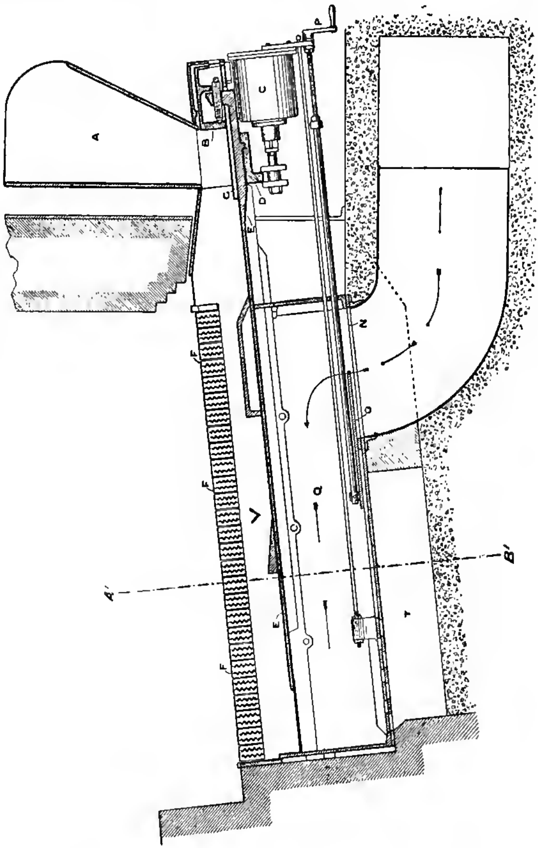


FIG. 17.

1 inch, according to the size of the furnace. The method adopted for giving this motion to the fire-bars is as follows. Two longitudinal bars *H* are fitted in the furnace, one on either side of the retort. These are

provided with projections, which engage the cast-iron lugs on the under side of the movable fire-bars. The crosshead

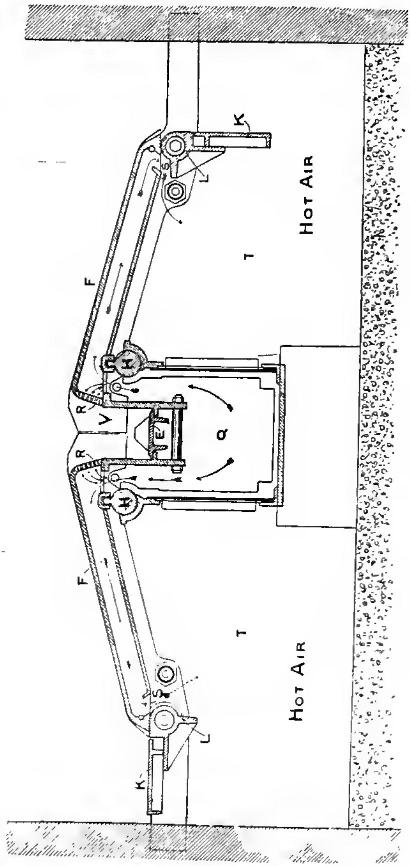


Fig. 18.

D is fitted with two nuts which each work in spirals fitted to the rocking bars, so that the reciprocating motion of the piston supplies the movement necessary

to twist them to and fro. The motion of the bars not only spreads the coked fuel over the grate, but the ash

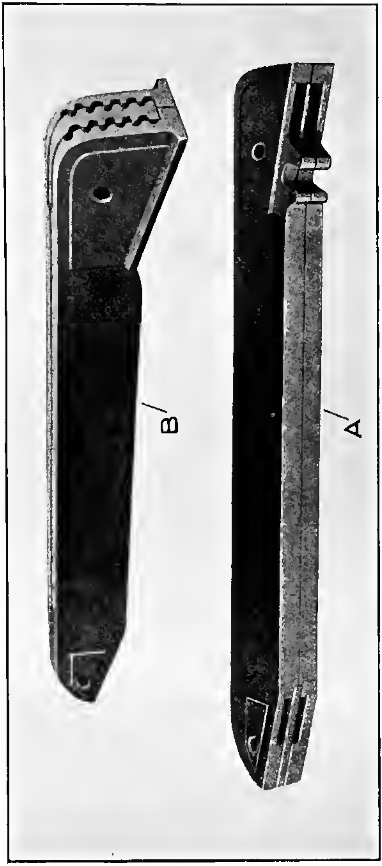


FIG. 19.

and clinker is discharged over the outer ends of the bars, when it falls upon the plates *K*. These plates are hinged, and from time to time, as the ash, etc.,

accumulates, they may be cleared by giving the hinge-bar L a twist, and so dumping the ashes into the ash-pit

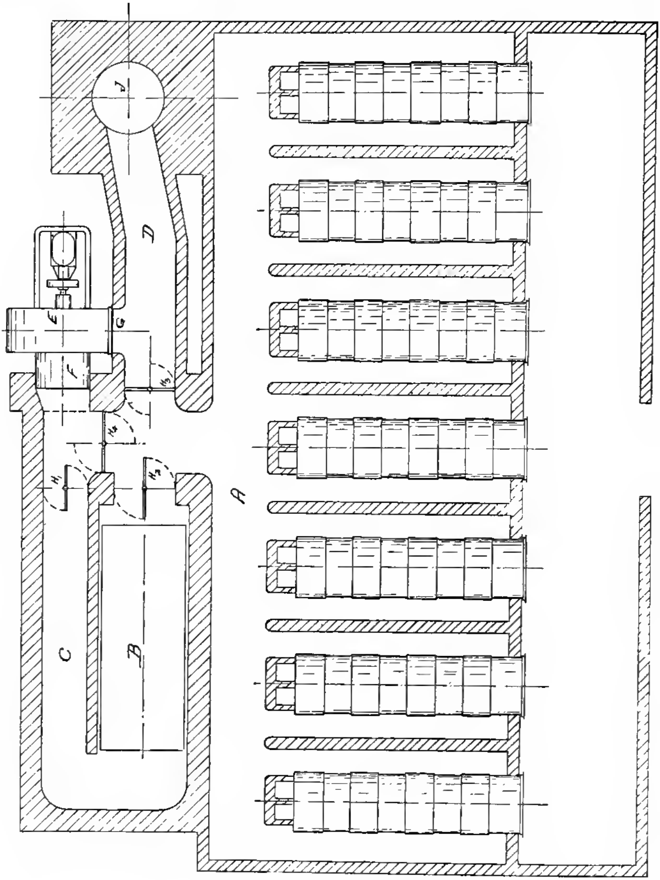


FIG. 20.

below. These hinge-bars are extended through the front of the furnace, and are provided with handles expressly for this purpose. A detail to be noted in this

stoker is the system of air distribution. Air from a fan is delivered under pressure through the duct *N* into the wind-box *Q*, and the aperture through which it enters is controlled by a flat valve *O*, which is adjusted by means of a screw and crank handle *P*. The air, after entering, passes up both sides of the retort, and some proceeds through the apertures *R*, while the remainder goes along the passage in the bars, where it finds an exit at *S*. While passing through these, it will attain a temperature of about 300° to 400° F., and at the same time this air will prevent the bars from becoming overheated. After leaving the bars through the apertures *S*, it is forced into the chambers *T*, from whence it proceeds through the spaces between the fire-bars into the fuel. An illustration of the fire-bars employed is given in Fig. 19, where *A* is a movable bar and *B* a fixed one. The moving bar is easily recognised by the lugs cast upon the under side. By using this furnace very fine slack can be efficiently burned.

A simple arrangement for an induced draught plant is seen in Fig. 20, which is a plan of a very successful installation in existence at the present time. This plant consists of seven Lancashire boilers in one house.

A is the main flue.
B ,, an economiser.
C ,, a flue for gases after leaving *B*.
D ,, the flue into chimney.
E ,, an induced draught fan and engine.
F ,, fan inlet.
G ,, ,, outlet.
H_1 H_2 H_3 H_4 are dampers.
J is the chimney.

From the arrangement depicted in this figure, it will be noticed that, by means of the dampers provided, the flue gases may be constrained to flow in three different directions. For ordinary working conditions dampers H_1 and H_2 will be open, while H_3 and H_4 will be closed. With this arrangement of dampers the gases will first proceed through the economiser, then along C to the fan inlet F, and will pass thence into the chimney. Should it be necessary for the economiser to be laid off for cleaning or repairs, the dampers H_1 and H_2 can be closed and H_4 opened. The products of combustion will then go directly to the fan inlet, and be discharged into the chimney as before. If, from a like cause, it is necessary to lay off the fan, then by closing dampers H_1 H_2 and H_4 and opening H_3 the chimney is put into immediate communication with the boilers. It is necessary to design the flues to be able to make these alterations to the course of the gases, so that in the event of any accident to the plant it is possible to avoid a complete stoppage of the works. In the figure the fan is driven by a steam engine, but of course it may be belt driven, or coupled to an electric motor. The writer prefers the first method, as it appears to be the most economical, especially if the exhaust steam from the engine is used for first stage heating of the feed water before it enters the economiser. Furthermore, if the plant is driven by an electric motor, the current for which is taken from an outside source, it is possible to put the full force of the draught on the boilers at any time. There is considerable danger in this, for after a works has been shut down for a time, say at an annual holiday or other similar occasion, the boilers will be cold, and steam should be raised very gently, especially in the

case of Lancashire or Cornish boilers. Under these circumstances, the fires should be only subjected to the draught of the chimney, and even if this is too fierce it should be adequately controlled by dampers. With an electrically-driven induced draught fan there would be a temptation to unduly force the fires, with the inevitable result that bad straining of the boilers would take place. If a steam-driven plant is employed, obviously it could not be started until the boilers had been at work for some little time, and there was a certain amount of pressure in them.

The class of engine most suitable for driving mechanical draught plant is worth while considering. There are three types from which to make a selection, namely, the ordinary open type quick-running engine, the single-acting high-speed engine, and the double-acting high-speed engine. Where cost of plant is of primary importance the first type named will usually be found to be the least expensive, although not always so, as they usually run at a slower speed than the other types, and consequently the size of the fan is increased, which adds to its cost, so that the combined plant may not offer so great an advantage in price as might be expected. Usually the fan will be placed in the boiler-house, which militates against this type of engine, as the dirt and dust, from which it is impossible to keep a boiler-house free, will settle on the engine and gradually work its way into the bearings, causing trouble from heated journals.

In the writer's opinion, the second type mentioned, that is the single-acting engine, has advantages for this class of work not possessed by either of its rivals. With the double-acting type, it shares the advantage

that it is totally enclosed, and therefore proof against troubles that might be caused by dust and dirt. The lubrication is carried out on the splash system, that is, the working parts, which are enclosed in a cast-iron case, run into a bath composed of oil and water. By this means all the bearings are flooded with oil automatically, which does away with any mechanical complications, such as pipe connections and feeding boxes, necessary for the lubrication of the other types. If properly designed, these engines will run noiselessly for years, without any attention being paid to the brasses, because, even when these wear considerably, the engine will still continue to run silently. These engines, being single acting, naturally require double the cylinder area that is necessary in the case of the other types, and in the larger sizes this considerably adds to the first cost, but the possible increased economy fully justifies the higher price.

The third type has come very much to the fore of late years, and may be run at considerably higher speeds than either of the other two. The motion work is entirely encased, as in the single-acting engine. The lubrication is carried out by means of an oil force pump, from which pipes are carried to each of the engine bearings, and along which oil is delivered under a pressure of about 15 to 20 lbs. per square inch. These engines will run for long periods without attention, beyond changing the oil strainer and keeping the oil up to its correct level, which, being under pressure, not only efficiently lubricates the journals, but also acts as a cushion, and keeps the engine quiet. Fig. 21 is an outline drawing of a fan for induced draught, coupled directly to a double-acting engine. There are several

points worth noting. In the first place, the bearing nearest to the fan is water jacketed, which is done in order to prevent the heat from the gases raising the temperature of the bearing, and causing the brass to seize on its journal. Another good feature about this plant should be noted, namely that the engine is separated from the fan by a short length of shafting,

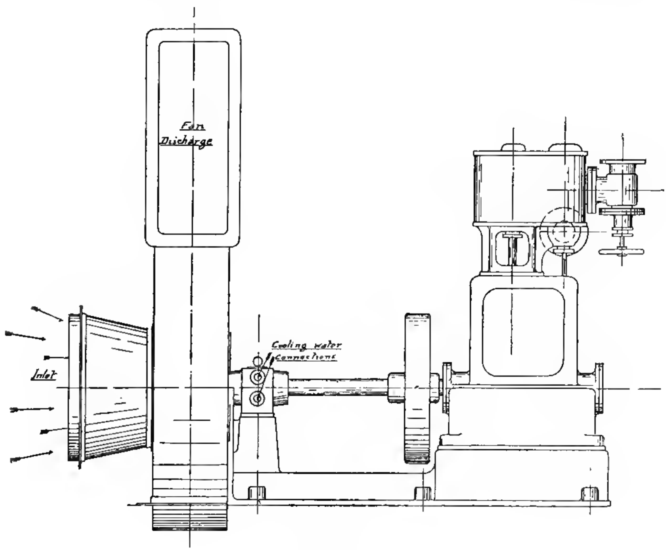


Fig. 21.

which is done to prevent the heat working along by conduction to the crankshaft and heating up that portion which works in the engine bearing, where it would be likely to cause trouble. A further matter that should be given careful attention is to see that the casing is adequately stayed and strengthened with angle irons wherever necessary. This is an essential point, because

the heat from the gases tends to distort the casing, and causes the fan to scrape against it if it is not properly strengthened. Such details as these are worth consideration, as they enable the plant to work for long periods with minimum of risk of breakdown. Sometimes it is more convenient to drive the fan by an electric motor. The best plan is to arrange for this to be coupled direct to the fan, in the same manner as the engine already described. It is not so satisfactory to have the fan driven by belt from the motor. In the first place, there is the loss in the belt drive, which may be anything from 7 to 9 per cent. of the power required to drive the fan, and which entails a constant loss as long as the plant is in existence. Then there is the probability of belt troubles, and perhaps delay from this cause which may be very serious. Against this is to be set off the gain in the first cost of the motor, which, on account of its higher speed, will be smaller, and consequently less expensive.

The Ellis & Eaves system of induced draught provides a means for heating the air on its way to the furnaces. The gases, on leaving the boiler, pass through an air heating box and from thence to the fan, which discharges them directly into the chimney. The air heating apparatus is comprised of a lot of tubes placed in large boxes. The hot gases from the boilers enter these boxes and circulate round the tubes, while the fresh air on its way to the boiler goes through the interior of them. By this arrangement the gases give up some of their heat to the air required for combustion, which in some cases is raised in temperature 250° F., or more. The passage of the air through the boilers is easily followed. First, the cold air enters the heating boxes,

where it is raised in temperature as explained, and is then conveyed through suitable ducts to the boiler fronts, where it enters the furnaces, the fan providing the necessary draught. Afterwards the gases are drawn along by it through the heater, and discharged into the chimney.

It has already been mentioned that a danger attending the use of forced draught is the possibility that the flames may blow back and seriously injure a fireman. There is no danger of this kind attached to induced draught in any form, but it has the disadvantage that the moment the furnace door is opened a large volume of cold air rushes into it. This causes a sudden cooling of the boiler plates, which is injurious.

Messrs. Davy Brothers, of Sheffield, have patented a modification of the Ellis & Eaves system, in which the air pressure in the furnaces is maintained at zero, so that there is no tendency either for the flames to blow back, or for excessive entry of cold air into the furnace. The name given to this system is that of Balanced Draught, and it consists of two fans, an air heating box or economiser and the necessary ducts. One fan is for forced draught, and provides a sufficient air pressure to force the air through the heat economiser into the furnaces and through the fires. At this point the larger or induced draught fan comes into action, and draws away the gases from the boiler through the heater, whence they pass into the chimney. By a proper adjustment of the two fans a condition can be arrived at in which there is actually neither outrush of gases or inrush of cold air when the furnace doors are opened.

Fig. 22 illustrates the system of balanced draught

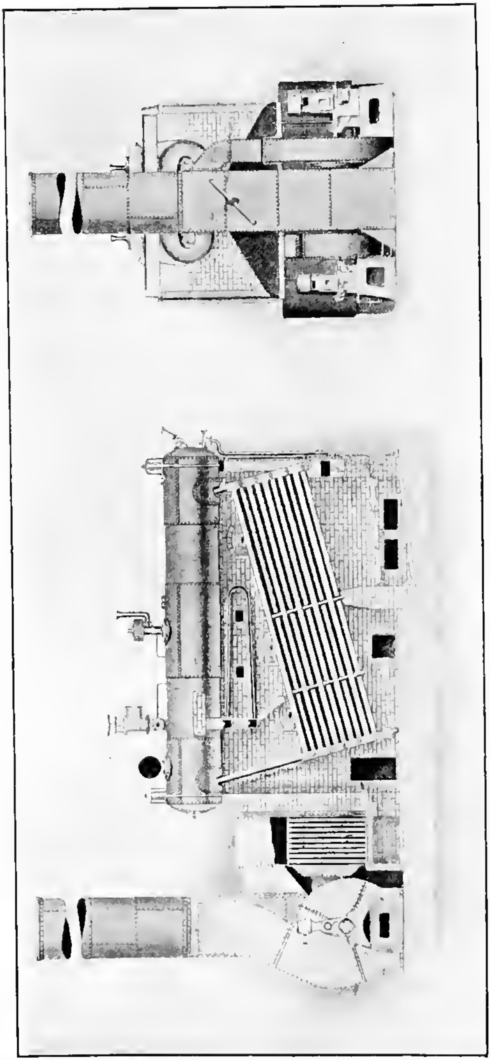


Fig. 22.

attached to a Babcock & Wilcox boiler. The air heater or heat economiser is seen behind the back wall of the boiler setting, in the left-hand view. The right-hand view clearly shows the two fans, the smaller of which deals with the cold air, while the larger one controls the hot gases.

CHAPTER X

THE APPLICATION OF MECHANICAL DRAUGHT IN MARINE PRACTICE

The matter contained in the foregoing chapters relating to the combustion of fuel, and methods of producing the necessary draught for it, has been considered from the standpoint of land installations.

Perhaps it would not be out of place to devote a few lines now to mechanical draught apparatus on board ship.

The calculations referring to land installations are equally applicable to marine work. A very simple method of arranging forced draught for a battery of marine boilers is the *plenum* system. In this, the boiler room is entirely closed, the air therein being maintained, by means of an open running fan, at a higher pressure than the atmosphere, usually about 2 inches. The fan is placed on one side of the bulkhead and the engine on the other, by which arrangement the fan draws its air from the atmosphere and discharges it from its periphery into the boiler-room. This arrangement is seen in Fig. 23, which is a drawing illustrating a single-acting engine coupled up to a fan of this type. It will be noted that the latter has no casing, consequently the mechanical efficiency of this design is not very high. When owners are willing to go to the expense, it is better to employ a steel-cased fan, either placed entirely outside the stoke-

hold and discharging into it through a duct, or else to have the casing bolted directly against the bulkhead, the relative position of the fan and engine being exactly

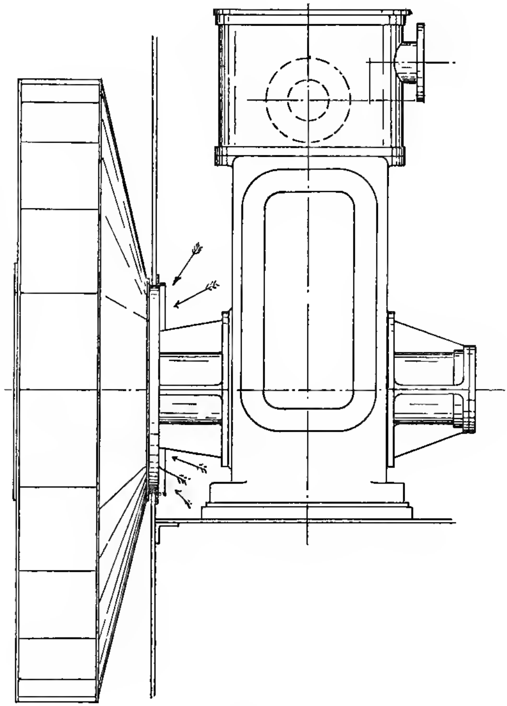


FIG. 23.

similar to that shown in Fig. 23. If this is done, the fan should be designed to discharge downwards.

Messrs. Davy Brothers' system of balanced draught, described on a previous page, can also be applied to a marine boiler with equal success. An instance of this is seen in Fig. 24.

The principle is exactly the same as that employed in the case of a land installation, but of course it necessitates

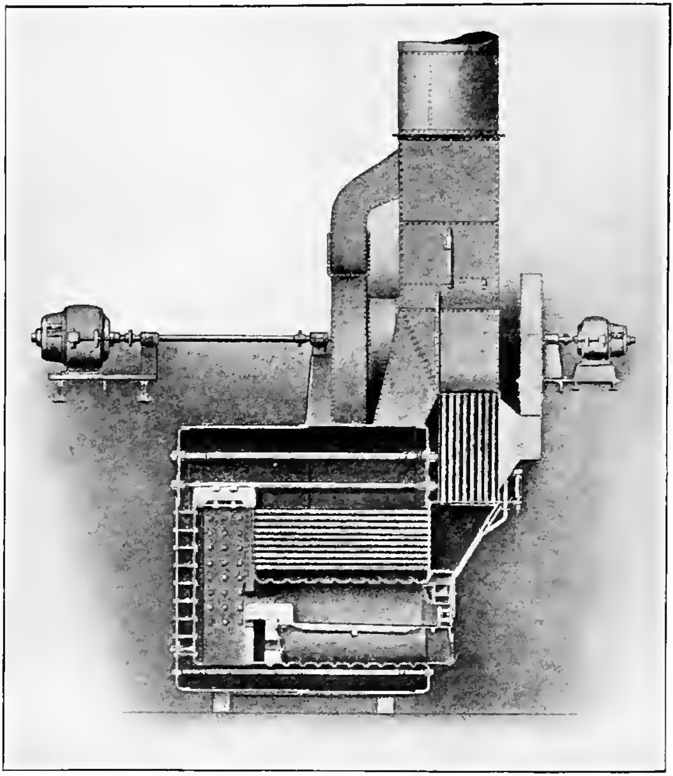


FIG. 24.

certain structural modifications to fit the different types of boilers used.

The Howden system of forced draught, already cursorily mentioned, is a great favourite with marine engineers.

In this type the ash-pits are closed, and in the uptake from each boiler, immediately above the outlet of the boiler tubes, that is, where they discharge the hot gases into the uptake, a group of air-heating tubes, arranged in a vertical position, is fixed. Through these tubes the hot gases pass, and the air for combustion, which is supplied under pressure by means of a fan, is forced amongst these tubes, and, being in contact with the outer surface of them, becomes heated before passing to the boiler furnace. The latter is fitted with a special door and door frame, so arranged that the hot air can be regulated both above and below the fires.

Some further remarks about this most successful system may be interesting, Many attempts to establish the use of forced combustion in boilers had been made before the Howden system was invented, in the United Kingdom, Holland, and America, but principally in the last named place. There the system of forcing air directly into closed ash-pits, also of exhausting the gases by means of a fan at the base of the funnel (induced draught), and by the use of compressed air in air-tight stokeholds, had been employed, but no very successful scheme was devised and eventually most were given up. This happened between 1830 and 1870. The introduction of the Howden system dates from 1884. From the first application of this it has been a remarkable and continuous success. Several thousands of installations have been fitted, and, as already mentioned, they are principally to be found in steamers, but there are a considerable number of installations also on land boilers. The makers claim that at least 30 per cent. greater steaming power may be expected, and that the economy is increased (that is, the steam evaporated per lb. of

coal) from 10 per cent. to 15 per cent. Amongst the other advantages claimed for this system is that the boilers do not deteriorate to the same extent as with natural draught. This is accounted for by the more uniform temperature maintained in the furnaces, and partly by the fact that no cold air can ever enter the furnace during the working period, so that the straining occasioned when cold air enters a boiler furnace while the fireman is stoking is obviated in this system. The method by which the entrance of cold air is prevented is as follows: When the furnace doors are opened the air pressure in the ash-pit immediately ceases, and only the hot air from the upper air supply passes into the furnaces, first in a direction vertically downwards, thereby forming a hot screen over the furnace mouth and preventing access of cold air.

CHAPTER XI

THE CHEMISTRY OF COMBUSTION

ALTHOUGH combustion has a wider significance, it means, in relation to the subject matter of this work, the burning of some carbonaceous fuel, so that the carbon contained therein will be combined with oxygen, with the result that heat will be generated and eventually used for raising steam. The principal fuels employed for the purpose are coal, coke, lignite, petroleum oil, wood, straw, and wood waste from sawmills. The percentage of pure carbon in these fuels varies greatly. Good Welsh anthracite contains the greatest percentage of carbon in any coal yet discovered, and is about 93 per cent. The following table gives the approximate amount of carbon in various fuels.

TABLE IX.

PERCENTAGE OF CARBON IN DIFFERENT FUELS.

Fuel.	Carbon.
Welsh anthracite . .	93 %
Semi-bituminous . .	82 to 88 %
Bituminous . . .	65 to 80 %
Lignite. . . .	50 to 70 %
Petroleum . . .	85 %
Coke	92 to 95 %
Wood	50 %
Wood refuse . . .	50 %
Straw	36 %

The oxygen required for combustion is obtained from the atmosphere, which, as already mentioned, consists of 21 parts of oxygen to 79 parts of nitrogen by volume. Nitrogen is quite useless for the purposes of combustion, the oxygen therefore being the only constituent which need be taken into account. It is a colourless, odourless and tasteless gas, with a density slightly greater than air, namely about 1·1 times heavier than the latter. Before going further, it will be useful to consider the atomic theory of chemistry, in order to appreciate the subject matter of this chapter. It is known that combinations of any of the elements, in certain fixed proportions, have always the same result. An instance will perhaps make this clear. The first example that comes to mind, and at the same time perhaps the simplest, is seen in the composition of water. This consists, as is generally known, of the chemical combination of hydrogen and oxygen, in the proportions of two parts by *volume* of hydrogen, to one part by *volume* of oxygen. The chemical symbol of this is

$$H_2O$$

The combination of these two elements in this definite proportion alone will form water. Thus, if a vessel were filled with three parts of hydrogen and one of oxygen, it would be found that the mixture would burn, and on examining the results of the combustion it would be found that one part of hydrogen remained, and that only two parts *exactly* had combined with the oxygen to form water. These proportions remain the same, for the most minute as well as for the largest volumes. The particle of the smallest dimensions used in chemistry is known as an atom, and the result of combining these atoms to form a new substance is designated a molecule.

Thus, considering the above example, if two atoms of hydrogen had been combined with one atom of oxygen, the result would have been one molecule of water.

The lightest gas known is hydrogen, and this is taken as unity in order to compare its atomic weight with that of other substances, and also to be able to compare these latter together. The atomic or combining weights of the principal elements found in fuel are given in Table X.

TABLE X.

COMBINING WEIGHTS OF ELEMENTS IN FUEL.

Name.	Combining Weight.	Symbol.
Hydrogen . .	1	*H*
Oxygen . .	16	*O*
Nitrogen . .	14	*N*
Carbon . .	12	*C*
Sulphur . .	32	*S*

These weights are invaluable to a chemist, for by means of them he is able exactly to determine the amount of the various materials that he requires to form any new substance. From the above table it is seen that oxygen is sixteen times heavier than hydrogen, so that the proportions by weight of these elements to form water is

$$2 \times 1 \text{ to } 16$$

i.e. $1 \text{ to } 8$

or, the weight of oxygen necessary is eight times that of hydrogen.

The chemical combinations most intimately connected with the boiler-house are those in which carbon, oxygen,

and hydrogen are found. By the union of the last two water is obtained, as already pointed out. The carbon and oxygen combine in two different proportions to form carbon monoxide or carbonic oxide, a most actively poisonous gas, and carbon dioxide. The latter is not poisonous, but it is quite useless for supporting life, and would cause death by suffocation. The symbol for the former gas is $C\,O$, and for the latter $C\,O_2$. From the first symbol we observe that carbon monoxide is evolved by the combination of equal *volumes* of carbon and oxygen, thus carbon monoxide $= C + O$.

It has been seen that their combining weights are 12 and 16 respectively, therefore we have carbon monoxide $= C + O = 12 + 16 = 28$.

In boiler furnaces the highest efficiency is aimed at, and in order to get this the carbon must be combined with sufficient oxygen to form $C\,O_2$, because this combination gives off 14,500 B. Th. U, whereas the former only gives off 4,400 B. Th. U. Now to form carbon dioxide twice the amount of oxygen is necessary as was required to form carbon monoxide, so that the total weight of the combination is carbon dioxide $= C + 2O = 12 + (2 \times 16) = 44$. This signifies complete combustion, because carbon will not combine with more than two parts of oxygen.

From the foregoing lines it will be seen that it is a comparatively simple matter to calculate the amount of oxygen required per lb. of carbon consumed, and from this the theoretical amount of air necessary. It has just been shown that carbon dioxide always contains

Carbon 12 parts,

and Oxygen $2 \times 16 = 32$ parts,

therefore the weight of oxygen required to form CO_2 in combination with 1 lb. of carbon is

$$O = 1 \times \frac{32}{12}$$
$$= 2\tfrac{2}{3} \text{ lbs.}$$

The weight of air that is necessary to supply this oxygen, on the assumption that the atmosphere is composed of 21 parts of oxygen to 79 of nitrogen by volume, can be found as follows:—

It is seen from Table X. that the combining weights of these two elements are respectively 16 and 14, therefore it follows that the proportion by *weight* of these elements in the atmosphere is

Oxygen = 23 parts
Nitrogen = 77 ,,

in round numbers, therefore the air required will be composed as follows:—

Oxygen	=	2·667 lbs.
Nitrogen	=	8·928 ,,
Total	=	11·595 ,,

say, for convenience, 11·6 lbs.

It is impossible to give the actual sequence of the conditions that obtain in a boiler furnace, because so much depends upon the air supply, the thickness of the fires, and the manner in which the air supply is adjusted. After a new lot of coal is spread upon the incandescent fuel already on the grate the heat from this drives off the combined constituents of hydrogen and carbon, known as hydrocarbons, and of which the chief are Marsh gas or Methane, and Ethylene, known as olefiant gas. These are denoted by the symbols CH_4 and C_2H_4 respectively. Ignition of these takes place at a low temperature, and

the heat generated helps to bring up the body of fuel to incandescence again. When this condition exists, the hydrocarbons will have been completely driven off, and the residue will be fixed carbon and ash. In order to assist the combustion of the hydrocarbons a certain amount of air will be necessary, which is usually supplied by adjusting the louvres fixed upon the furnace doors. This furnishes the requisite oxygen, which combines with the volatile constituents of the fuel to form water with the hydrogen, and $C\,O_2$ with the carbon. This air is also necessary for another reason, as it is quite likely that the gases, on leaving the bed of fuel, contain a fair proportion of $C\,O$, which needs a certain amount of oxygen to convert it into $C\,O_2$. Too much air admitted to the fires will cool the gases, and, in the early stages of combustion, will produce smoke, but too little air will also conduce to the emission of smoke. When thick fires are used more air is necessary above the fuel than with thin ones, but at the same time the total air required for combustion will be less.

Carbon greedily combines with oxygen, and if there is a sufficient supply of the latter it will form $C\,O_2$, but if there is not the necessary oxygen then the $C\,O_2$ will take up another atom of carbon, and carbon monoxide will be formed. By means of the usual symbols, chemists show this change thus –

$$C\,O_2 + C = 2\,C\,O,$$

from which it is seen that one part each by volume of $C\,O_2$ and C form two parts of $C\,O$. This is easily proved as follows. It has been shown that the combining weight of $C\,O_2$ is 44, while that of C is 12, therefore we have

$$44 + 12 = 2\,(12 + 16),$$
$$56 = 2 \times 28 = 56.$$

Now $C O$ can be ignited without any difficulty, but it requires oxygen to assist its combustion. During the process each molecule of $C O$ will take up another atom of oxygen, and, combining with it, will again form $C O_2$ thus

$$C O + O = C O_2.$$

It is probable that these alterations between $C O$ and $C O_2$ take place many times in succession during the passage of the gases through the bed of fuel in the furnace, but the final conversion will be to $C O_2$ where the combustion is complete. The actual combustion of a lb. of coal is a much more complex process than that of a lb. of pure carbon, on account of the various constituents that are found in its composition. The most important of these are hydrogen and carbon, but also nitrogen, sulphur, oxygen, ash, and moisture are to be found. Complete combustion will result in the union of the carbon with oxygen to form carbon dioxide, then the hydrogen and oxygen in the fuel will combine to form water, which will pass off in the form of highly gaseous or superheated steam. The remaining hydrogen will combine with external oxygen, and will give off heat during the process. If there is sulphur in the fuel, sulphurous and sulphuric acids, $S O_2$ and $H_2 S O_4$ respectively, will be formed. These acids have a very deleterious effect upon steel and iron, causing excessive corrosion. They sometimes become deposited by condensation upon the tubes of an economiser, or upon the blades of an induced draught fan, causing rapid deterioration. For this reason it is inadvisable to use any forced draught apparatus in which steam jets are employed if the percentage of sulphur in the fuel is large. The moisture supplied by the jets assists in forming these acids.

Table XI. gives the analysis of a sample of bituminous fuel.

TABLE XI.

Constituents.	Percentage.
H . . .	5·4
O . . .	8·1
C . . .	80·3
N . . .	2·1
S . . .	1·4
Ash . .	2·7

It will be interesting to calculate the actual amount of air theoretically required, for the complete combustion of a lb. of coal of the above composition. A portion of the hydrogen will combine with the oxygen in the coal, the amount of which can be easily determined, because it has been shown that the amount of oxygen necessary is eight times that of the hydrogen. The oxygen contained in the above sample is 0·081 lbs., therefore the weight of hydrogen that this will combine with is

$$\frac{0{\cdot}081}{8} = {\cdot}0101 \text{ lbs.}$$

The amount of hydrogen that remains to be combined with the oxygen of the atmosphere is therefore

$$0{\cdot}054 - {\cdot}0101$$
$$= {\cdot}0439 \text{ lbs,}$$

and consequently the weight of oxygen that is required to combine with this hydrogen is

$${\cdot}0439 \times 8 = 0{\cdot}3512 \text{ lbs.}$$

The carbon is the next constituent that commands attention. It has already been seen that 1 lb. of this requires 2·667 lbs. of oxygen for complete combustion

into CO_2. Now there is 0·803 lbs. of carbon in the sample, therefore the weight of oxygen necessary is

$$0{\cdot}803 \times 2{\cdot}667$$
$$= 2{\cdot}1416 \text{ lbs.}$$

The nitrogen undergoes no change, and the only effect that it has is that it tends to decrease the temperature of the gases by taking away some of the heat to raise its own temperature. It is seen that the sulphur in the sample amounts to 0·014 lb.. The combining weight of sulphur is 32, therefore, as that of oxygen is half of this, it follows that the actual weight of oxygen will be exactly the same as that of the sulphur, which is 0·014 lbs, seeing that two atoms of oxygen are required. It should therefore be noted that the total weight of oxygen required for the above sample of coal is

Oxygen required by hydrogen	= 0·3512	lbs.
,, ,, ,, carbon	= 2·1416	,,
,, ,, ,, sulphur	= 0·014	,,
Total	= 2·5068	,,

The weight of air necessary to supply this quantity is therefore

$$\text{Weight of air} = 2{\cdot}5068 \div \frac{23}{100}$$
$$= 10{\cdot}9 \text{ lbs.,}$$

and the volume of air that this weight represents at 32° F. is :

$$\text{Volume of air} = 10{\cdot}9 \div 0{\cdot}0807$$
$$= 135 \text{ cubic feet.}$$

It was pointed out in a former chapter that the actual air used was always in excess of the theoretical amount required, and that the extra amount is known as the air required for dilution. This excess is often 100 per cent. of the theoretical amount, and sometimes even very much

more. It follows, therefore, that in actual practice great accuracy in the above calculations is not essential, but it is a useful guide in settling upon the size of a draught plant, where fuels of widely-varying constituents have to be dealt with.

The amount of air actually used per lb. of fuel burnt can, of course, be measured, if suitable arrangements are made. It is, however, often inconvenient to do this, and to get over the difficulty a chemical analysis of the gases may be resorted to; in fact, many prefer this method to that of actual air measurement. It is a simple matter to obtain the percentage of $C\,O$, $C\,O_2$, and O in any sample of gas by using an apparatus designed by Orsat and named after him. A full description of this appliance, and the method of using it, will be given subsequently. When the percentage of the three gases named above has been determined, the remaining gas nitrogen can be calculated thus

$$N = 100 - (C\,O_2 + C\,O + O).$$

A sample of furnace gases was taken by the writer, when making a test on a water-tube boiler, some time ago. The analysis showed that this sample was composed of

$$C\,O_2 = 10{\cdot}79 \text{ per cent.}$$
$$C\,O = 0{\cdot}8 \quad ,,$$
$$O = 7{\cdot}71 \quad ,,$$

therefore the nitrogen by deduction was

$$N = 100 - (10{\cdot}79 + 0{\cdot}8 + 7{\cdot}71)$$
$$= 80{\cdot}7 \text{ per cent.}$$

It has been seen that the atomic weight of $C\,O_2$ is $12 + (2 \times 16) = 44$, therefore it is obvious that the proportion of carbon in a volume of $C\,O_2$ is

$$\text{Carbon} = \frac{12}{44} = \frac{3}{11}$$

while similarly that of oxygen is

$$\text{Oxygen} = \frac{2 \times 16}{44} = \frac{32}{44} = \frac{8}{11}.$$

As the atomic weight of $C\,O$ is 28, the proportion of carbon in this gas is

$$\text{Carbon} = \frac{12}{28} = \frac{3}{7}$$

and of oxygen

$$\text{Oxygen} = \frac{16}{28} = \frac{4}{7}.$$

For convenience in working it is assumed that a volume of 100 cubic feet of this sample of gas is under consideration, and so there will be

10·79	cubic	feet of	$C\,O_2$
0·8	,,	,,	$C\,O$
7·71	,,	,,	O
80·7	,,	,,	N

It will now be necessary to convert these volumes into weights, and to enable this to be accomplished the specific density will be required, which may be found in the following table :—

TABLE XII.

Name of Gas.	Density.	Cubic Feet per lb.	Specific Heat at Constant Pressure.
Air . . .	0·0807	12·38	0·238
Carbon monoxide .	0·0781	12·8	0·248
Carbon dioxide .	0·1234	8·1	0·216
Hydrogen . .	0·0056	178·8	3·405
Oxygen . . .	0·0893	11·2	0·218
Nitrogen . .	0·0784	12·72	0·244
Light hydrocarbons	0·0806	12·41	0·593

Now multiply each volume by its corresponding specific density, and this will give the actual weight of each gas in the sample. It will then be found that the

CO_2 weighs $10{\cdot}79 \times 0{\cdot}1234 = 1{\cdot}33148$ lbs.
CO „ $0{\cdot}8 \times 0{\cdot}0781 = 0{\cdot}06248$ „
O „ $7.71 \times 0{\cdot}0893 = 0{\cdot}6885$ „
N „ $80{\cdot}7 \times 0{\cdot}0784 = 6{\cdot}32688$ „

The proportions of oxygen and carbon that exist in these gases have already been investigated. It will now be necessary to determine the total weight of oxygen required to produce this sample, and it is found to be

$$\text{Oxygen in } CO_2 = 1{\cdot}33148 \times \frac{8}{11} = {\cdot}96834 \text{ lb.}$$

$$\text{,, } \quad CO = {\cdot}06248 \times \frac{4}{7} = {\cdot}0357 \text{ ,,}$$

$$\text{Uncombined O} \quad . \quad . \quad . \quad = {\cdot}6885 \text{ ,,}$$

$$\text{Total oxygen} = 1{\cdot}69254 \text{ lbs.}$$

In a similar manner the weight of carbon may be obtained thus—

$$\text{Carbon in } CO_2 = 1{\cdot}33148 \times \frac{3}{11} = {\cdot}36314 \text{ lb.}$$

$$\text{,, } \quad \text{,, } \quad = {\cdot}06284 \times \frac{3}{7} = {\cdot}02693 \text{ ,,}$$

$$\text{Total carbon} = {\cdot}39007 \text{ lb.}$$

As there is 0·23 lb. of oxygen in a lb. of air, the weight of air necessary to supply this quantity of oxygen is:

$$\text{Weight of air} = 1{\cdot}69254 \div 0{\cdot}23$$
$$= 7{\cdot}36 \text{ lbs.}$$

The total carbon consumed was 0·39007 lb., and the weight of air necessary to supply sufficient oxygen to produce this sample of gas is seen to be 7·36 lbs., there-

fore the air required for 1 lb. of carbon under similar conditions is:

$$\text{Weight of air per lb. of carbon} = \frac{7{\cdot}36}{0{\cdot}39007}$$
$$= 18{\cdot}87 \text{ lbs.}$$

The above gives the amount of air required for pure carbon. If the coal used in this test had contained 88 per cent. of carbon, then the amount of air necessary per lb. of fuel would be—

$$\text{Weight of air} = 18{\cdot}87 \times {\cdot}88$$
$$= 16{\cdot}605 \text{ lbs.}$$

There would be some additional air required for combination with the hydrogen given off, because there was not sufficient oxygen in the fuel to render it inert.

The air theoretically required per lb. of coal used on this test was 11·88 lbs., so that the amount required for dilution, neglecting the weight necessary for combination with the surplus hydrogen in the fuel, was:

$$\text{Air for dilution} = 16{\cdot}605 - 11{\cdot}88$$
$$= 4{\cdot}725$$

that is 28·6 per cent. of the total air used.

Although coal is made up of the various constituents already named, yet different classes of it contain these in varying proportions. Knowing the latter, it is possible to calculate the heating or calorific value of any particular fuel. This heating value is given in British thermal units. As the density of water varies for different temperatures, the amount of heat that will raise 1 lb. one degree will vary, therefore it is necessary to fix a particular temperature, which is 62° F.

As already stated, when 1 lb. of carbon is completely burned to form $C\,O_2$, then 14,500 British thermal units are emitted, and if only one atom of O is taken up

by the carbon then $C\,O$ results, and only 4,400 units of heat are given off. Again, if 1 lb. of hydrogen is burned with 8 lbs. of oxygen the result will be 9 lbs. of water, and the heat available amounts in this case to 62,100 units. One of the hydrocarbons given off when coal is burned is methane ($C\,H_4$), usually termed marsh gas. Knowing the heat values of carbon and hydrogen when burned in air, it is quite easy to calculate the heat value of 1 lb. of gases compounded of these two elements. Suppose 1 lb. of $C\,H_4$ is taken as an example. Here there are 12 parts by weight of carbon and $(1 \times 4) = 4$ of hydrogen, and therefore the proportion of carbon present by weight is

$$C = \frac{12}{12+4} = \frac{12}{16} = \frac{3}{4}$$

while the hydrogen is

$$H = \frac{4}{12+4} = \frac{4}{16} = \frac{1}{4}$$

so that the heat units given out when 1 lb. of this gas is burned will be

$$\begin{aligned} \text{Heat units from carbon} &= 14{,}500 \times \frac{3}{4} = 10{,}875 \\ \text{,, \quad ,, \quad hydrogen} &= 62{,}100 \times \frac{1}{4} = 15{,}526 \\ \text{Total heat units emitted} &= 26{,}400 \end{aligned}$$

Taking the same example of fuel that was made use of for an example when it was shown how to calculate the theoretical amount of air required, it will be interesting to find out what the calorific value of it is. Seeing that the carbon contained is 0·803 lb., the heat liberated on the complete combustion to $C\,O_2$ will be:

$$\begin{aligned} \text{Heat units} &= 14{,}500 \times C \\ &= 14{,}500 \times \cdot 803 \\ &= 11{,}643 \text{ B. Th. U.} \end{aligned}$$

A lb. of this coal contains 0·054 lb. of hydrogen and 0·081 lbs. of oxygen. Now it has been shown that the oxygen renders inert one-eighth of its weight of hydrogen, therefore only the balance of the hydrogen will be available as a source of calorific power. It is usually supposed that the combination of the oxygen in the fuel with the hydrogen obtained from the same source does not contribute to its calorific value, which may be true, therefore the calorific value of the hydrogen that remains after the oxygen in the fuel is used up in British thermal units is

$$\text{Heat units} = 62{,}100 \left(H - \frac{O}{8} \right),$$

which in the example under consideration works out to

$$\text{Heat units} = 62{,}100 \left(\cdot054 - \frac{\cdot081}{8} \right)$$
$$= 2{,}726.$$

so that the total heating value of this example is:

Heat emitted by the combustion of carbon	= 11,643
" " " hydrogen	= 2,726
Total calorific value	= 14,369

The two separate calculations given above can be combined, which, when expressed as a formula, become

$$\text{Calorific value} = 14{,}500\, C + 62{,}100 \left(H - \frac{O}{8} \right).$$

The heat units developed when 1 lb. of hydrogen combines with oxygen are 4·28 times more than when carbon and oxygen combine. This formula can therefore be written

$$\text{Calorific value} = 14{,}500 \left\{ C + 4{\cdot}28 \left(H - \frac{O}{8} \right) \right\},$$

which is the form most commonly seen in text-books on the subject. Another useful figure that can be obtained

from the calorific value of fuel is known as the evaporative power. It is a number which signifies the lbs. of water that can theoretically be evaporated from and at 212° F. by the heat units in the fuel. Now it requires 966 heat units to evaporate 1 lb. of water under these conditions, therefore the evaporative power is the heat units in the coal divided by this number, and is expressed thus—

$$E = \frac{14{,}500}{966}\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$
$$= 15\left\{C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right\}$$

where E is the evaporative power.

A form of calorimeter often used for determining the calorific value of fuels is that known as the Lewis Thompson calorimeter. It consists of a glass vessel, specially graduated, a copper furnace to hold the fuel, and a copper combustion chamber fitted with a tap, also a metal base for this chamber, fitted with a clutch spring. A thermometer must be provided capable of registering temperatures to one-tenth of a Fahrenheit degree. In Fig. 25 a diagrammatic sketch of the apparatus will be found, in which

A is the glass vessel,
B is the copper combustion chamber.
C is the metal base.
D is the copper furnace.

The last-named has been shown in the figure dotted, because, when the apparatus is at work, this is contained inside the combustion chamber, and so is invisible. The following lines describe the method of using the apparatus :—

A quantity of fuel is first carefully ground to very fine

powder, and 2 grammes are taken for the purpose of the test. To supply the oxygen necessary for combustion a mixture consisting of three parts of chlorate of potash and one part of nitrate of potash is required. The 2 grammes of fuel must be mixed thoroughly with about twelve times this weight of the mixture, and the whole placed in the copper furnace. It must then be firmly pressed with a rammer provided for the purpose. The furnace ought next to be placed in the recess in the base, and a small piece of fuse placed on the mixture. The next thing is to fill the glass vessel with sufficient water, until it rises to a mark engraved upon it. The temperature of this water must now be very carefully taken with the finely graduated thermometer already mentioned. The fuse should now be lighted, and the combustion chamber, with the cock closed, placed over the furnace and pressed firmly down until the clutch spring holds it securely in position. Then the whole should immediately be submerged in the water contained in the glass vessel. This operation must be performed as quickly as possible, or the experiment will be useless, as much of the heat given off by the fuel will be dissipated in the atmosphere. As soon as the combustion ceases the cock on the combustion chamber should be opened, to allow the water to rise into it, so that the inside and outside are at the same temperature. Then the thermometer must be placed in the water, and the rise of temperature

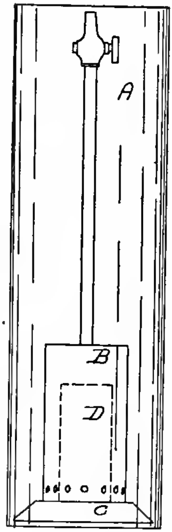


FIG. 25.

noted very carefully. To the rise of temperature registered 10 per cent. must be added to make up for the heat lost in the apparatus itself. As the weight of water and rise of temperature are known, it is easy to calculate the thermal units given off by the combustion of 2 grammes of fuel, and it is just a question of simple proportion to arrive at the units of heat contained in 1 lb. of similar coal.

The following table gives the average percentage of the principal constituents in various classes of fuel, together with the calorific value and evaporative power.

TABLE XIII.

Class of Fuel.	*C.*	*H.*	*O.*	*E.*	*B.Th.U.*
Charcoal . . .	·93	—	—	14·0	13,500
Coke, good . .	·94	—	—	14·0	13,620
,, medium . .	·88	—	—	13·2	12,760
,, bad . . .	·82	—	—	12·3	11,890
Coal, anthracite .	·915	·035	·026	15·75	15,225
,, dry bituminous.	·9	·04	·02	15·9	15,370
,, ,, .	·77	·05	·06	14·25	13,775
,, caking . .	·88	·052	·054	16·0	15,587
,, ,, . .	·81	·052	·04	15·15	14,645
,, cannel . .	·84	·056	·08	15·6	15,080
,, dry long flame .	·77	·052	·15	13·65	13,195
,, lignite . .	·7	·051	·2	12·15	11,745
Peat, kiln dried . .	·6	·07	·3	11·12	10,716
,, air ,, . .	·46	·05	·24	8·185	7,911
Wood, kiln ,, . .	·5	·06	·42	10·09	7,715
,, air ,, . .	·4	·05	·33	6·58	3,522
Mineral oil . .	·85	·15	0	22·5	21,634

The properties and characteristics of these different fuels are worthy of notice. The first on the list is

charcoal, its composition being of pure carbon and ash. It does not contain any hydrogen or oxygen, and its employment is confined to special processes, being too expensive for general use. When burned it gives off intense heat if supplied with sufficient air, and does not flame, but gradually becomes incandescent. Coke is made from special classes of coal, those brands only being suitable which cake easily. It is the residue left after all the hydrocarbons in the coal have been driven off, which is done by placing the coal in a retort or coke oven and applying heat thereto. The most familiar sources from which coke is obtained are the various gas-works, although the best is produced in properly constructed ovens. At collieries that produce a suitable class of coal for the purpose, the making of coke is often an important part of the business. During the process of manufacture, the gases that are distilled are passed through specially designed recovery plant, where sulphate of ammonia and benzine $C_6 H_6$ are obtained. The gas that remains, being inflammable, may then be conducted to gas engines, where it is employed to develop power. Only the smaller coals are generally used in the ovens, the process of distillation forming the loose slack into a solid lump, which is withdrawn from the ovens and broken into pieces of a convenient size. The weight of coke obtained from coal varies from about 35 or 40 per cent. to 65 or 70 per cent. The proportion of carbon in the finished article is from 88 to 93 per cent. Like charcoal, it does not flame to any extent, but gives off great heat. It is principally used in foundry cupolas, smelting furnaces or gas producers, and is not often employed in the furnaces of boilers.

The coal which contains the least amount of impurities

is South Wales anthracite, the percentage of carbon being very high. It is a very hard coal, and often when broken its surface presents a highly polished appearance. It is very difficult to burn, and requires a strong draught to keep it alight. Being free from tarry matters, it burns without smoke and gives off practically no flame. On account of its freedom from impurities, it is greatly in demand at breweries for drying malt, and of late years this demand has considerably increased, owing to the introduction of the suction gas producer, its freedom from tar being specially valuable when the gas generated is used in internal-combustion engines. Of the dry bituminous fuels, the South Wales steam coal is the best example. This coal is mined in the same coalfield as the anthracite, but in the eastern end. It is a very hard coal, containing a high percentage of carbon, has great calorific value, and is used in the Navy exclusively. The combustion is almost smokeless, only short flames being produced, and it is intensely hot, but requires, like anthracite, efficient draught. It is quite a striking sight, when visiting the South Wales coalfield, to notice the freedom from smoke at the collieries, as rarely more than a very light brown vapour is emitted from the chimneys. The caking coals are mined in the Newcastle district, and are rather a troublesome fuel to burn satisfactorily. As their name implies, they have a tendency to form solid masses on the fire-bars, and give a lot of trouble to the boiler attendant.

Cannel coal, which is found in Lanarkshire and some parts of Lancashire and Warwickshire, burns with a long flame. It contains a very much greater quantity of volatile hydrocarbons than the other classes, and is much in demand at gas-works for the production of town's gas.

It will now be useful to describe a practical method of making an analysis of the gases that are formed by the combustion of fuel. The more generally used type of the Orsat gas analysing apparatus is that known as the Orsat-

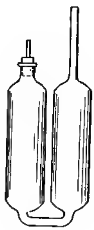


FIG. 26A.

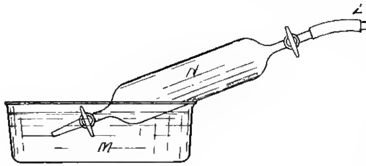
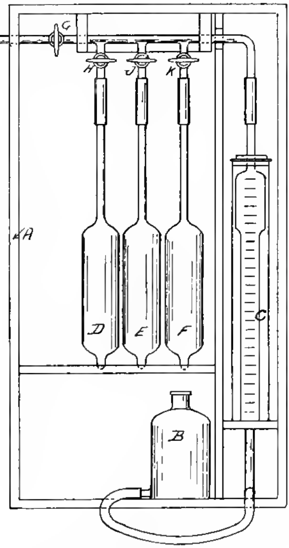



FIG. 26.

Fischer set, made by Messrs. Townson & Merser. This is shown in Fig. 26 and consists of the following :—

A a wooden containing case,

B a level bottle.

C a water jacketed burette,

D, *E* and *F* absorption cylinders or flasks filled with glass tubes,

G, *H*, *J* and *K* stop-cocks,

L connection for sample of gas.

The burette *C* is calibrated for 100 cubic centimetres, and consists of an inner measuring tube placed inside a

glass cylinder. The annular space between the two is filled with water, in order to keep the temperature constant. The level bottle *B* is required to control the movement of the sample of gas. It should be almost filled with water to which has been added a considerable quantity of common salt.

The absorption flasks each contain a certain number of glass tubes, and various solutions are poured into them, each solution absorbing a particular gas. Thus *F* contains a solution of caustic potash which will absorb CO_2, while the second flask *E* contains an alkaline pyrogallate solution, and absorbs the oxygen. In the third flask is put a concentrated solution of cuprous chloride in hydrochloric acid, which will take up any CO that is in the sample.

The stop-cocks *G*, *H*, *J* and *K* are employed to control the distribution of the gases.

The flasks *D*, *E* and *F* are all exactly similar, and a side view of one of them is given in Fig. 26A. It will be noted that there are two cylinders in reality, joined together at their bases, and that the one which is not connected to the burette is fitted with a cork, through which a glass tube is pushed. This latter is required to allow of ingress and egress of the air necessary to compensate for the varying level of the solutions when the instrument is being used. The quantity of solution placed in these flasks should be just sufficient to rather more than half fill them. The various connections throughout the apparatus are made with india-rubber piping, and care should be exercised to see that all these are in good condition and air-tight before making an analysis. The stop-cocks may with advantage be smeared with vaseline to prevent leakage.

The method of using this apparatus is explained in the following lines :—

First of all the stop-cocks *H*, *J* and *K* should be closed, then *G* opened, and the level bottle *B* raised so that the water flows from it into *C*, filling the latter and also the various connecting tubes, until it dribbles out at *L*. When this happens, the cock *G* must be turned off, and the level bottle placed on the top of the case, in order to set free the operator's hands for other work. Assuming that the sample of gas has already been procured, the receptacle containing it should be fixed to *L* by means of the shortest possible piece of rubber piping. Now the stop-cock in the latter must be opened, and also the one marked *G*, at the same time lowering the level bottle. The water will then flow back into it, and the gases will be drawn into the apparatus. The level bottle should be still further lowered until the water stands at zero in the burette. In the figure, a glass sampling flask is shown connected up ready for use. It will be seen to have a cock at both ends, and also that the one end stands in a receptacle which contains water. This is necessary because, as the water is lowered in the burette, the gases would be at a lower pressure than the atmosphere, and so, to prevent this, water to which salt has been added is placed in the bowl *M*. This will flow into the sampling flask *N* as the gases are withdrawn. When operating both cocks on *N* should, of course, be opened. Before the sample enters the apparatus, the solutions in the absorption flasks should be drawn up by using the level bottle to create a slight vacuum until they stand just below the stop-cocks. The actual analysis is made as follows :—

The stop-cock *K* is opened, and 100 cubic centimetres

of the sample that is already in the apparatus is forced into the flask F, which is done by raising the level bottle B until the water rises in C to the 100 cubic centimetre mark. Then K is shut again, and the sample is left for a short time in F, just long enough for the solution to properly absorb the CO_2. When a sufficient time has been allowed for this, the level bottle should be lowered, and K opened. The solution will rise again in the one half of the absorption flask, and the level of it must be adjusted to the same place as it occupied before the sample was forced into it. On looking at the burette it will be seen that the water has not gone back to zero, but stands some distance up the scale. The number of cubic centimetres occupied by the water represents the volume of CO_2 that has been extracted from the sample. After this test has been completed, the sample must next be forced into the flask E to extract the oxygen, and then into D to obtain the percentage of carbon monoxide. When making these tests it is necessary to exercise care, in order to be certain that the sample inside the apparatus is at atmospheric pressure. To ensure this, it is essential that, whenever a reading is taken in C, the level bottle is so held as to make the level of the liquid in the burettes and in the bottle identical, otherwise the results obtained will be misleading.

To make the foregoing quite clear, assume that a sample of gas has been taken, which has duly been drawn into the apparatus as described above. It is forced first into F, and on being withdrawn the water is found to stand at a height of 14·5 divisions in the burette, and, as the latter is calibrated for 100 cubic centimetres, it is therefore obvious that the sample contains 14·5 per cent. of CO_2 It is next forced into E,

and upon being withdrawn the water is seen to stand at 21·3 in the burette. The percentage of oxygen in the sample is therefore

$$\text{Percentage of oxygen} = 21{\cdot}3 - 14{\cdot}5$$
$$= 6{\cdot}8 \text{ per cent.}$$

The gas is next brought into contact with the solution in *D*, and afterwards the water in the burette reaches the 22nd division exactly, so that the $C\,O$ in the sample is 0·7 per cent. of the volume. Consequently the remainder, which is practically all nitrogen, is 78 per cent. of the whole. It will be well to touch upon the methods employed to obtain the samples of gas from the flues. A small wrought-iron pipe should be inserted through the brickwork, and should be long enough to reach well into the stream of gases as they flow on their way to the chimney. The flask to contain the gases should be attached to the other end of this pipe where it projects through the outside of the brickwork of the flue. It has already been pointed out that these flasks are fitted with a stop-cock at either end, the one not attached to the iron pipe being connected to an aspirator. This latter is worked by means of a supply of water under slight pressure, which can be obtained from the nearest available source. If there is no water main near at hand, a tin vessel capable of holding a few gallons may be used. This should be fixed a sufficient distance above the aspirator to give to the water a slight head, which must be not less than 4 feet. As soon as the water commences to fall through the aspirator, a partial vacuum will be created in the flask, which will cause the gases from the flue to flow into it. This should be kept in action sufficiently long to be certain that any air lingering in the iron pipe has been expelled and that

only flue gas is present, otherwise the data obtained will not be reliable.

When an aspirator is not available, the writer has found the following method very satisfactory. Two flasks and a three-way cock should be obtained, and fitted up as seen in Fig. 27, where

A is the three-way cock.

B and *C* are the two flasks.

One branch of *A* is attached to the iron pipe, while the other two are each fixed to a flask. Previously to this

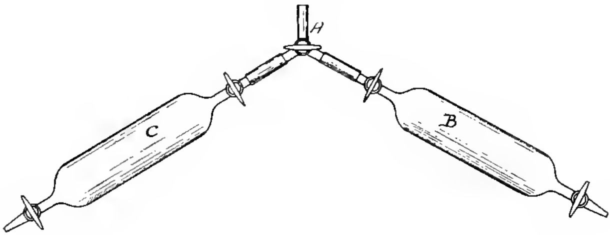


FIG. 27.

B and *C* should have been filled with salt and water (brine). After they are connected up, first of all the cock *A* should be turned on so as to allow *B* to communicate with the flue. Now both cocks fitted in *B* must be opened, when the water will run out and will be replaced by the flue gases, or any air that is lodged in the iron pipe and connections. This must be allowed to continue until only about 1 inch of water remains in *B*, when both the cocks will be closed. This sample is not for use, but it is taken in order to be assured that all connections are filled with undiluted flue gas. Now *A* must be adjusted so that *C* is in communication with the flues, and when this is done both cocks should be

opened as before and another sample taken, which is the one that has to be analysed. Some people prefer to use a special form of air-tight bellows, instead of either of the above methods. These bellows are fitted with a stop-cock, and should be opened and closed several times, after being fixed to the iron pipe. This will expel any air that remains in the bellows and pipes, and will ensure the obtaining of a reliable sample.

The Orsat apparatus just described is very useful for an occasional analysis of the gases, which alone is of great value, and it also has the advantage of being inexpensive. But it does not furnish a guide to enable the fireman to make such adjustments that he will obtain the best possible combustion under all conditions of draught, fuel, and load. With changing loads or varying qualities of fuel different quantities of air will be found necessary, and without a guide of some sort a boiler attendant is at a loss to know how properly to regulate the air supply to his furnaces. The surest indication of the completeness of combustion is the percentage of $C\,O_2$ that the gases contain. If it were possible to work with the exact amount of air theoretically required, then, when combustion was complete, the gases would contain about 21 per cent. of carbon dioxide. As these perfect conditions are impossible in a boiler furnace, the percentage is always considerably less than this. Where the brickwork leaks badly, or the boiler bridges are in a dilapidated condition, in fact where any defect exists by which air may leak into the flues, this, together with inefficient combustion, may bring down the percentage of carbon dioxide as low as 3 or 4 per cent., whereas, if everything is in first-class condition, it may be as high as 16 per cent. As already pointed

out, inefficient combustion is due either to too little, or to an excess of air. If there is too little, then smoke is produced, and $C O$ will be found in the gases. Should there be too much, then the temperature of the furnaces will be lessened. Both of these conditions reduce the heat given up by the fuel to the water. Then again, if a factory is in a district where by-laws for the restriction of smoke are rigidly enforced, a stoker will be tempted to allow an excess of air over the fires, to save his employers being fined and himself getting blamed and perhaps dismissed. By having a suitable apparatus at hand, it is both possible to obtain more efficient combustion, and also to prevent undue emission of smoke. There are instruments at present on the market which are expressly designed to give the fireman this assistance, and they are known as $C O_2$ recorders.

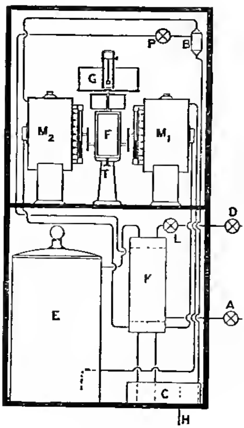


FIG. 28.

The following description of one made by the Cambridge Scientific Instrument Company will give some idea of how this class of instrument is worked. An illustration of the apparatus is seen in Fig. 28, in which

A is the water inlet to recorder.
B is an aspirator.
C is a water vessel.
D is the gas inlet to the recorder.
E is an absorption box.

F, *G*, the recording mechanism.

K is a gas cooler.

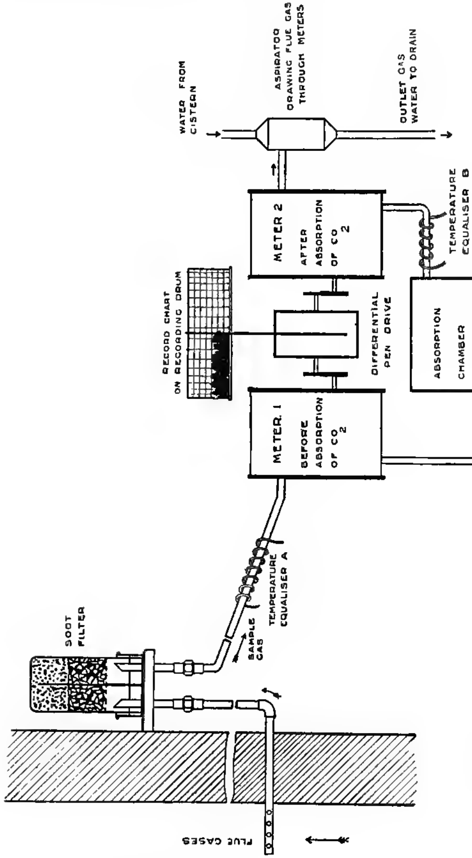


FIG. 29

L is an air-valve.

M_1 & M_2 are two gas-meters.

Fig. 29 is a diagram of the necessary connections. An iron pipe is fixed in the wall of the boiler flue, in the

same way as described in the case of the Orsat test, which should be perforated as shown. Immediately above it is fixed a bracket upon which rests a soot filter. This consists of a vessel divided vertically by a thin diaphragm, and packed with wood shavings and wood wool, also another lower vessel which contains water and acts as a water seal. The gas from the flues enters on one side of the diaphragm, passes through the filtering material, and leaves by the pipe on the other side. The whole apparatus should be arranged so that there is a slight fall in the pipe that leads from the filter to the recorder, in the direction of the latter. The instrument operates in the following manner. The aspirator B is started, which draws gas from the filter into the apparatus through the gas inlet D. It first goes into the cooler K, which consists of a series of water-cooled pipes, and thence into the meter M_1. From here the gas flows through the absorption box E, which is filled with lime and absorbs the CO_2. During this process the gas becomes heated, and in order to reduce it to the original temperature, it is passed through a second chamber in K. It then goes into meter M_2 and, as the CO_2 has been extracted, M_2 will register a smaller volume of gas than M_1. Now these meters are connected through differential gearing to the recording mechanism F and G, which will cause the pen of the recorder to rise and fall by an amount depending upon the CO_2 in the gases. The recorder is fitted with a drum which carries paper, and upon it a chart is traced, showing the CO_2 at any moment of the day. After leaving M_2 the gases pass to the aspirator, and are discharged with the water into the vessel C.

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